STELLAR WONDERS

GLOBULAR CLUSTER M3 CANES VENATICI, APRIL 9, 1910.

(Mount Wilson Observatory, California.)

Frontispiece

Astron
V

STELLAR WONDERS

BY

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PREFACE

Most of the talks contained in this volume were given several years ago, at the British Broadcasting Station, Aberdeen. To publish them now in book form is an experiment in presenting to the public some results of astronomical research. The information has been carefully brought up to date, and will, I hope, be found useful to those interested in Astronomy. It is hoped that the book, even with its errors (if some should remain after careful revision) and omissions, may be the means of fostering an intelligent interest in the wonders that lie stored in the depths of infinite space.

Among the many sources from which information has been drawn in the preparation of this volume, I acknowledge my especial indebtedness to the *Scientific American* publications, *Journals of the British Astronomical Association*, *Monthly Notices of the Royal Astronomical Society*, "Popular Astronomy," "Universe of Stars," by Harvard Observatory, and "Stellar Astronomy." Acknowledgment must also be made of the most valuable assistance and suggestions rendered by the Rev. Martin Davidson, D.Sc., F.R.A.S., and Peter Doig, F.R.A.S., Editor of the *British Astronomical Journal*.

Charles Whyte.

The Manse,
Kingswells,
Aberdeen.
November 12, 1932.

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CHAPTER I

THE HISTORY OF THE TELESCOPE

No instrument has done more to widen the scope of human knowledge, to extend our ideas of the universe, and to stimulate the activity of the intellect, than the telescope, unless the microscope be regarded as a successful rival. But even admitting an equality in scientific importance, the former instrument is much more interesting in its history, in the same degree that its history is more simple and more comprehensible. To trace its development from an insignificant affair in the hands of its discoverer to the present time is to be brought into contact with some of the great philosophers from the seventeenth century onwards who have attained greatness in physical science —Galileo, Newton, Kepler, Huygens, Cassini, Hadley, Fraunhofer, the Herschels, father and son—to mention a few only from the list of great names. I purpose in this chapter to review briefly the origin and development of this powerful help in the study of nature, to name a few of the important achievements depending upon it, and to trace its gradual improvement up to the magnificent instruments of the present day.

Galileo learned in 1609, while visiting Venice, that a wonderful instrument had been invented the preceding year in Holland, by means of which an observer would be able to view a distant object with the same distinctness as if it were only at a small fraction of its real distance. It required but little time for this great genius to master the problem thus

suggested to his mind, and after his return to Padua, where he held the position of Professor of Mathematics in the famous University of that city, he set himself earnestly to work making telescopes. Such was his success that in August of the same year he sent to the Venetian Senate a more satisfactory instrument than they had been able to procure from Holland; and in January of the next year, by means of a telescope magnifying thirty times, he discovered the four satellites of Jupiter. This brilliant discovery was followed by that of the mountains in the Moon, of the variable phases of Venus, and of the real nature of the Milky Way. Though Galileo did not change the character of the telescope as it was known to its discoverer in Holland, he made it more perfect. Thus the form which he used is to this day known as the Galilean telescope. Considering the great interest excited throughout Europe by the invention of the telescope, it is surprising that its early history is confused. The invention has been attributed to Archimedes, to Roger Bacon, to Porta, and to many others who have written on optics. It seems to be well established now, however, that John Lippershey, or Lippersheim, a spectacle-maker at Middleburg, was the real inventor of the telescope, and that Galileo's first telescope, suggested by news of the Hollander's achievement, was an independent invention.

This discovery was evidently an accident, for not only was there no developed theory of optics at that time, but even the law of refraction, which lies at the basis of such theory, was quite unknown. It also appears certain that Galileo's invention must have been guided by somewhat precise information, such as that the instrument consisted essentially of two

lenses, of which one was a magnifying and the other a diminishing lens.

Three reasons may be given for holding this belief: (1) Galileo's telescope was not unlike that of the Hollander's; (2) it is not so simple as that made of two magnifying lenses, as is proved by the fact that Kepler, the first philosopher to establish an approximate theory of optical instruments, only two years later, invented the latter and prevailing form; and (3) Galileo published no contributions to the theory of optics. But, in any case, Galileo's merit is in no way lessened by his having failed to do what could not be done at that time.

No other discoveries of great moment were made until more than a generation afterwards Galileo proved the existence of spots on the Sun in 1611. This cessation of activity was doubtless owing to the difficulty of securing telescopes of greater efficiency than that possessed by Galileo, which he would scarcely have left until its powers of discovery had been fully exhausted in his own hands. By the middle of the seventeenth century, however, several makers of lenses had so far improved the methods of grinding and polishing, that telescopes notably superior in power to that of Galileo were obtainable. Of these, Torricelli, Divini, and Campani (all Italians), Auzout and Huygens, have won distinction as telescope-makers. The last-named philosopher discovered, by means of a telescope of his own construction, the largest satellite of Saturn in 1655, thus adding a fifth member to the list of planetary bodies unknown to the ancients.

But his most important astronomical discovery, made also in 1655, was the nature of the rings of Saturn. This object had greatly puzzled Galileo, to

whose small telescope the planet appeared to consist of a larger sphere flanked on either side by a smaller one; but when, in the course of the orbital motion of Saturn, the rings entirely disappeared, he was quite unable to suggest an explanation. This planet had thus presented a remarkable problem to all astronomical observers for half a century, and the records of the efforts to solve it during that interval supply us with the best means of judging the progress in practical optics. Huygens announced these discoveries early in 1656, but that relating to the ring was given in the form of an anagram, the solution of which was first published in 1659. This discovery was questioned in Italy by Divini, but was finally confirmed by members of the Florentine Academy with one of Divini's own telescopes.

Some years after this, the famous astronomer Cassini, having come to Paris from Italy as Royal Astronomer, began a series of brilliant discoveries with telescopes made by Campani of Rome. With these, varying in length from 35 to 136 feet, he discovered four satellites to Saturn in addition to the one discovered by Huygens. The total number was increased by Herschel's discovery of two smaller ones in 1789, one hundred and five years after Cassini's last discovery, and again by Bond's discovery of an eighth in 1848. The Saturnian system thus serves as a record of the successive improvements of the telescope. It is worthy of note that the discoveries of the eighteenth century were made with a reflecting telescope, the others all being with refracting instruments.

Cassini's discovery in 1684 of the two satellites now known as Tethys and Dione was not accepted as conclusive until a number of years after, when Pound in 1718, with a telescope 123 feet in length, which

Huygens had made and presented to the Royal Society, saw five. This particular instrument is of great interest, because it is the only one of those of the last half of the seventeenth century which has been carefully compared with modern instruments. But although it had a diameter of 6 inches, its performance was not nearly so good as that of a perfect modern telescope of 4 inches in diameter and $4\frac{1}{2}$ feet in length; while in regard to convenience in use the modern compact instrument is much superior.

Another notable discovery of this period was that of the duplicity of the rings of Saturn by Cassini in 1675. Cassini's discovery, however, of the third and fourth satellites of Saturn must be regarded as marking the farthest reach of the old form of telescope. A century was to elapse and an entirely new form of telescope was to be developed before another considerable addition to our knowledge of the aspect of the stars was to be made.

Let us now turn our attention to a form of telescope in which the image is formed by reflection from a concave mirror. Newton constructed a small one with his own hands which is still in the possession of the Royal Society. This little instrument is of about the same magnifying power as the instrument with which Galileo discovered the satellites of Jupiter seems to have been, but it is only about $6\frac{1}{2}$ inches in length.

Since that time the reflecting telescope has had a remarkable history of development in the hands of a number of skilful mechanicians, who have also, in a large degree, been distinguished by their discoveries in physical astronomy.

After Newton's invention was made public little was done towards the improvement of telescopes for

half a century, until Hadley presented a reflector with a parabolic mirror of his own construction to the Royal Society in 1723, which was found to be practically equal to the Huygens refractor of 123 feet in length. From this time we may date the beginning of the superiority of reflectors. A few years later, James Short of Edinburgh began his career as a practical optician, and for thirty years he was unapproached in the excellence of his instruments. During this time many telescopes, more powerful than the best of the previous century and much more convenient in use, had been made and scattered throughout Europe, but during this period also there was a singular dearth of telescopic discovery.

Sir William Herschel was born in 1738 in Hanover. In 1755 he left his native country, and, going to England, secured in 1766 a position as organist in the Octagon Chapel, Bath. Here he became so profoundly interested in the views of the heavens which a borrowed telescope of moderate magnifying power yielded that he tried to purchase one in London. He had not the means, however, to buy a satisfactory instrument, so he determined to construct one with his own hands. Thus he entered upon a course which was to reflect honour upon himself, his country, and his age, and which was to add more to physical astronomy than any other man had added before. With almost inconceivable industry and perseverance, he cast, ground, and polished more than four hundred mirrors for telescopes, varying in diameter from 6 to 48 inches. Early in his career he made an important discovery, which attracted universal attention. On the night of March 13, 1781, Herschel was examining small stars in the constellation of Gemini with one of his telescopes of a little more than

6 inches in diameter, when he perceived one that appeared visibly larger than the rest. This proved to be a new world, now known as Uranus. The discovery led, in the following year, to his appointment as Astronomer to the King, George III., with a salary which, with proceeds of sales of telescopes, was sufficient to enable him to devote his whole time to astronomy.

One of the fruits of this increased leisure was the construction of a telescope far more powerful than had been thought of by his predecessors—it was 4 feet in diameter and 40 feet in length. Herschel commenced to build it in the year 1785, and on the date of its completion—August 28, 1789—he verified by its means a sixth satellite of Saturn, and, less than a month later, a seventh, even closer to the planet and smaller than the sixth.

There has been one improvement in the reflecting telescope since the time of Herschel which deserves to be noticed here—namely, the replacing of the heavy metal mirror by one of glass, made even more highly reflective than the old mirrors by a thin coating of silver deposited by chemical methods upon the polished glass. The great advantage of this modern form of reflector lies not so much in the greater lightness and rigidity of the material as in the fact that the surface, when tarnished, can be renewed by the simple process of replacing the old silver film by a new one; whereas in the metal reflectors a tarnished surface required a repetition of the most difficult and critical portion of the whole process of construction.

We must now go back to a quarter of a century before Herschel discovered the new planet Uranus, in order to trace the history of another form of telescope which has remained unrivalled in the more

difficult fields of astronomical research, and which to-day finds its most perfect development in the great instruments at the Observatories of Greenwich, Vienna, Pulkowa, Mount Hamilton, Lick, Washington, and Yerkes. It is called the achromatic telescope.

Newton had declared, as a result of his experiments, that separation of white light into its constituent colours was an inevitable accompaniment of deviation by refraction, and consequently the shortening of the unwieldy refractors was impracticable. The correctness of the experiment remained unquestioned for nearly a century, but a famous mathematician, Euler, cast doubts upon the conclusion. His argument was that, since the eye produces colourless images of white objects, it might be possible, by the proper selection of curves, so to combine lenses of glass and of water as to produce a telescope free from the colour defect. Although Euler's premise was an error, since the eye is not free from chromatic dispersion, his efforts had the effect of leading to much more critical study of the phenomena involved. In this, John Dollond, a well-known optician in London, met with great success. Repeating an experiment of Newton's with a prism of water opposed by a prism of glass, he found that deviation of light could be produced without accompanying dispersion into prismatic colours. He also found that the two varieties of glass—crown or common window glass and flint glass, which is characterized by the presence of a greater or less quantity of lead oxide—possessed different powers in respect of dispersion. Thus, of two prisms of these two varieties of glass which would deflect the light through the same angle, that made of

flint glass would form a spectrum nearly twice as long as the other. Hence, if a prism of crown glass deflecting a transmitted beam of light, say, 10 degrees, were combined with one of flint glass which would deflect the beam of light 5 degrees in the opposite direction, there would remain a deflection of 5 degrees with very little dispersion into colour. It also follows that a positive lens of crown combined with a negative lens of flint of half the power would yield an almost colourless image. Such combinations of two different substances are called achromatic systems.

It is a singular fact, worth noting in passing, that more than twenty years before Dollond's success, Mr. Chester Moor Hall had invented and made achromatic telescopes, but this remained unknown to the world of science until after Dollond's telescopes had become famous.

For a long time this ingenious invention of achromatic telescopes remained fruitless for astronomical discovery on account of the impossibility of securing sufficiently large and perfect pieces of glass, more particularly of flint glass. It was not until after the beginning of last century that any real advance in this branch of the arts was exhibited. Even then success appeared, not in England or France, where every effort was made to improve the quality of optical glass, but in Switzerland. There a humble mechanic, a watchmaker, Guinand by name, spent many years in endeavouring to make large pieces of optical glass. In the year 1805 he joined the optical establishment of Fraunhofer in Munich. Here he remained nine years; and, with the increased means at his disposal and the aid of Fraunhofer, he perfected his methods so far that

the production of large discs of homogeneous glass became only a matter of time and cost—that is to say, all the large pieces of optical glass which have since been produced, whether in England, France, Germany, or America, have been made by direct heirs of the practical secrets of this Swiss watchmaker.

Fraunhofer was a genius of a high order. Although he died at the early age of thirty-nine, he had not only brought the achromatic telescope to a degree of optical perfection which made it a rival of the most powerful of the reflector type, and so far improved its method of mounting that his system has replaced all others, but he also made some excellent discoveries in the domain of physical optics. His great achievement was the construction of an achromatic telescope 9½ inches in diameter, with which the elder Struve made at Dorpat his remarkable series of discoveries and measurement of double and binary stars. The character of Struve's work demonstrates the excellence of the telescope, and shows us that it is to be ranked as the equal of all but the very best of its predecessors. Indeed, it may fairly be concluded that not more than one or two telescopes, and those made and used by Herschel, had ever been of greater power, while in convenience for use the new refractor was much superior.

For a long time, Fraunhofer and his successors, Merz and Mahler, from whom the great 15-inch telescopes of Pulkowa and of Harvard Observatories were procured, remained unrivalled in this field of optics. But they have been followed by a number of skilful constructors whose products have been scattered all over the world. Some of the most notable discoveries made with refractors are the satellites of Mars and the companion to Sirius.

But, besides these, there is a long list of double and binary stars of the most difficult character discovered by the late Professor Burnham, by Professor Robert Aitken, and by a number of other eminent observers.

In concluding this chapter, I should like to mention three things in favour of reflecting telescopes: First, they have done much in astronomical photography. By far the best photographs we have of any nebulæ have been made by the magnificent reflectors of the present day. Second, reflecting telescopes now seem to be increasingly popular. All the instruments of large size are of that type, the latest being the projected 200-inch giant reflector to be erected in California. Third, the construction is so comparatively simple that an efficient reflector is far less expensive than are refracting telescopes of similar power, so that this may be regarded as particularly the amateur's telescope. The lens of a 12-inch refractor costs about £360. A 36-inch objective would probably cost about £10,000. Large mirrors cost about one-tenth as much as lenses of the same size. The great 100-inch reflector of the Mount Wilson Observatory cost, with its mounting, more than £100,000. The 200-inch reflector, however, which is to be constructed for research work in pure science will cost about £250,000, and remarkable results are confidently expected to be obtained from it.

CHAPTER II

LIGHT, HEAT, AND DURATION OF THE LIFE OF THE SUN

We shall deal in this chapter with one member only of the innumerable millions of stars in the universe, and a comparatively insignificant member when compared in absolute size and brightness with some other stars, and yet a member which is to us all-important, without whose presence and beneficent radiation all life on our planet would cease.

This, to us, all-important star, the Sun, has in all times and all ages excited the keenest interest and wonder in mankind. It was in several races invoked as one of the deities who ruled over mankind, and, indeed, though perhaps not realized to the full by its followers, sun-worship had a better basis for its existence so far as man's material welfare is concerned than any of the pagan religions.

In modern times we are only at the beginning in obtaining some idea of the real nature, constitution, and influence of the Sun. It was probably not until the discovery of spectrum analysis sixty-five years ago that the true nature of the Sun began to be dimly realized. Just as in the study of the stars the last twenty-five years have seen more advances in the study of the constitution, structure, and motions of the stellar universe than all preceding time, so the last thirty-five years of solar research have been more fruitful in teaching us the nature of this dominant orb, our Sun, than all the labours and speculations of earlier periods. And yet, just as in stellar astronomy the advances of the present would have

been impossible without the patient and painstaking observations of past generations, so, in solar research, we owe more than is generally realized to those who have carefully observed and faithfully recorded the visible phenomena of the Sun, and who have advanced theories to account for the observed facts. The importance of the problem of the constitution of the Sun is being more and more realized, not only by astronomers and scientists, but by representative governing bodies and the intelligent public.

If we look at the Sun through smoked glass we see an intensely bright disc with a sharp circular boundary, which is called "the limb," and sometimes with dark spots on its surface. If we use a telescope of higher and higher power, of course with the intensity suitably diminished by shade glasses or other means, we find that the outer boundary still appears perfectly sharp and circular; that we see many more spots; that the surface of the Sun, generally called the "photosphere," is not uniformly bright, but is mottled in a way that has led to its being called the "rice-grain structure"; and that some parts near the limb and also often near spots are much brighter than the general surface, such parts being called "faculæ." If these observations were continued we should find that the numbers and sizes of the spots and faculæ varied, that they passed through a complete cycle of change through maximum and minimum spottedness in a little over eleven years. Another evident fact of observation is that, in addition to the Sun's sending us a great deal of light, we also receive a considerable amount of heat.

In addition to these facts, let us recount a few well-known dimensions. The Sun, the diameter of which is 865,000 miles, is situated nearly 93 million

miles from us. Its volume is 1,306,000 that of the earth. A simple dynamical calculation based on the known times of revolution of the Moon around the earth, and of the earth-moon system around the Sun, shows that the Sun has 332,800 times the mass of the earth.

The density of the earth, which has been accurately determined, is 5·52 times that of water, and hence the Sun is 1·41 times as heavy as an equal volume of water. If expressed in pounds, the mass of the earth is 1317 followed by 22 ciphers; and of the Sun 438 followed by 28 ciphers. It readily follows that the attraction of the Sun at its surface is 27·6 times that of the earth at its surface, and a man weighing 150 pounds would weigh over 2 tons on the Sun.

The Sun being 93 million miles from the earth, it is evident, even to the least observing and thoughtful, that it must be exceedingly bright and hot to give such striking evidence of these effects at that enormous distance.

No doubt most of us have been present at a fire, and have noticed how quickly the heat diminished as we moved away; that even if unpleasantly hot at 100 yards it was quite comfortable at 200.

It seems quite reasonable to say that if the Sun radiates so much heat at 93 million miles, it must be hotter than any temperature attainable on the earth. There is every reason to believe that the temperature of the visible radiating photosphere was, in the unknown ages of the past, at a maximum of 9,000 degrees Centigrade, somewhat lower than Sirius, but it is now 6,200 degrees Centigrade, or 10,700 degrees Fahrenheit. Very probably the great central volume of the Sun is in a dense state owing to the tremendous pressure which exists there.

This view is strengthened by the enormous temperatures that must prevail in the inside of a globe whose outer visible surface is at a temperature of 6,200 degrees Centigrade. The deeper we go, the more rapidly does the temperature increase, until at the centre it amounts to probably tens of millions of degrees.

Charles G. Abbot, in his book on "The Sun," has elaborated a theory, first generally stated by Secchi, and contributed to by Schuster, which seems to explain in a satisfactory manner most solar phenomena. In this theory it is assumed that the Sun's surface, except perhaps in sunspots, is wholly gaseous and vaporous, the photosphere being too hot to contain solids or liquids. Further, the density of the gases rapidly diminishes, and their temperature quickly falls from within outwards across the apparent boundary of the Sun.

Rising higher above the photosphere are the prominences, which are apparently eruptions or outbursts of luminous gas which the spectrograph has shown are generally hydrogen and calcium. These were first seen at Eclipses, but can now be observed and photographed at any time. The prominences pass through a similar cycle to the spots, and are apparently related to them in some way, although even when there are no spots the Sun is never free from prominences. These prominences sometimes shoot up to the enormous height of 200,000 miles, occasionally reaching a velocity of 200 miles per second. They are probably striking confirmation of the disturbed condition of the interior of the Sun. But besides these tremendous eruptions, the spectroscope shows that the chromosphere—that is, the upper atmosphere of the Sun—and probably also the

photosphere, are rarely quiescent. Over and near sunspots, for instance, it is observed from the displacement of the spectral lines that the vapours are in motion.

It has been noticed that terrestrial magnetic storms are often nearly coincident with the celestial passage of a large sunspot over the Sun's disc. It seems evident that the striking similarity between the curves of spot numbers and the daily range of the terrestrial magnetic elements can be simply explained by the influence of the magnetic fields around sunspots.

It has been observed that spot vapours are at considerably lower temperatures than those over the surrounding photosphere. It has long been known that the spot spectrum is different from the ordinary solar spectrum. Some of the lines are widened and strengthened, some are weakened, some are doubled, and many fine lines not present in the photospheric spectrum are present in spots. In the case of the widened and weakened lines it was found that these lines behaved, in general, in a similar way in terrestrial spectra as in sunspots when the temperature of the vapours producing them was reduced, thus showing that the spot vapours are at a lower temperature.

It was further found that the numerous fine lines in the spot spectra were due to the formation of such compounds as magnesium, calcium, and titanium oxides, which can only exist at considerably lower temperatures than that of the photosphere. These facts formed convincing evidence that the vapours over sunspots were at lower temperatures than over the surrounding photosphere. A sunspot is the result of an eruption or other deep-seated cause of

which nothing is definitely known, which tends to produce rapid local upward movements of a column of gas from within the Sun towards the surface of the photosphere.

Maintenance of Sun's Heat

Helmholtz, in the last century, showed that the contraction of the Sun under the influence of its own gravitational force would suffice to maintain the present rate of radiation for many millions of years.

The Sun's own gravitational power is struggling constantly to draw every one of its particles to the centre of the Sun. It is subjected to its own immense compressive force. The immense quantity of energy represented by the actual motion of the Sun's materials inward toward the centre is converted into heat. These are such fruitful sources of heat that the Sun need contract no more than 250 feet every year at the present time to supply the radiation which goes out in all directions, and of which very little reaches us upon the earth. This is so slow a rate of solar contraction that we could not possibly observe any diminution in the Sun's diameter even with the most refined measuring apparatus until after the passing of some five thousand years. There can be no doubt that this solar compression would liberate sufficient heat to maintain the present rate of flow for 25 million years; but, by many consistent lines of work, geologists and astronomers have found ages for the earth and the Sun of many millions of years, much too long for the contraction theory. Though the contraction of the Sun upon its own material is probably a true source of energy, this, in itself, cannot explain its great radiative power

through the enormously long ages of the past which are absolutely necessary for the earth's geological changes.

Various theories of atomic disintegration or even annihilation of matter and its conversion into radiation have been advanced to account for the source of the enormous energy and duration of life of the Sun or of a star. The whole question is, however, one of extreme difficulty, and has not received a satisfactory solution.

I have by no means been able in this chapter to cover even a small fraction of the ground required adequately to treat this subject, but I hope sufficient has been said to give some idea of recent views on the constitution of our luminary, and to show you that we are probably on the threshold of very important discoveries, by improved methods, about this, to us, the most important star in the universe.

SPIRAL NEBULA M33 TRIANGULI.

(Mount Wilson Observatory, California.)

Facing p. 24

SUN, SHOWING SUNSPOT.

DRAWING OF A SUNSPOT BY NASMYTH.

Facing p. 25

CHAPTER III

SUNSPOTS: THEIR CONNECTION WITH AURORA BOREALIS

A SUNSPOT marks a focus of disturbance on the Sun's surface. It is not something permanent, but intermittent and transient. Every eleven years there are many and great sunspots on the Sun. They then decrease in number and size. This decrease is accompanied by a gradual change in position.

Sometimes spots or spot-groups are large enough to be seen with the unaided eye. Unaided is rather a misnomer, for nobody would think of looking at the Sun without some protective contrivance, such as smoked glass. But for the larger groups no magnifying power is necessary. A good field glass shows far more of the spots, provided that care be taken to hold the shade glass directly in front of the eye and not in front of the objective of the field glass. With this simple equipment the amateur may see the spots and observe their progress across the Sun's disc from day to day as the rotation carries them onward.

The Sun is a huge ball of gas, and it is a strange fact that it does not rotate as one piece, as in the case of the solid earth, but that the equatorial regions actually move round faster than regions more remote from the Sun's equator, the slowing down being a gradual process from the equator towards the poles. In the equatorial regions the Sun turns on its axis in about twenty-five days.

Sunspots are short-lived concerns, and even the

largest of them usually endure for only three or four months at most. Although they are nearly as short-lived as storms, they resemble storms in another way —they are far more likely to happen in some latitudes than in others. Spots are seldom found more than 45 degrees from the Sun's equator, and few of them beyond the 35th parallel of solar latitude. When their numbers are increasing toward the maximum, they take place in two sharply defined zones on each side of the equator, extending from about 15 degrees to 30 degrees of latitude, with a practically clear region almost 250,000 miles wide between them.

As the activity of the Sun increases and new spots appear in increasing number to replace those which become extinct, the spotted zones widen on the side towards the equator, until the vacant area between them becomes narrow. Then, after the maximum the zones shrink on their narrow edges, few or no new spots appearing in high altitudes to take the places of those which die out. Eventually, when the action has nearly faded away, the spots are practically confined to the region within 10 degrees of the Sun's equator. Before the last traces of spot activity have disappeared here, spots belonging to the new cycle break out between 25 and 30 degrees from the equator in new spot-zones about 400,000 miles apart. These zones widen as the number of spots increases, and so the cycle goes on. This remarkable behaviour, known as "Spoerer's Law," after its discoverer, is of much importance, for it indicates clearly that the sunspots are only symptoms of some deep-seated disturbance involving a great portion of the Sun.

A sunspot is not really black, but appears to be

so, because it is cooler than the hotter or brighter regions of the Sun below it. The earlier observers of the Sun called the sunspots "maculæ," or stains, the central darker interior, or "umbra," being surrounded by a less dark region called the "penumbra." The "penumbra" represents an outflow of the materials constituting a sunspot on to the surface of the Sun. These materials are the vapours of metals. The Sun's surface is so intensely hot—6,200 degrees Centigrade—that no substance, not even carbon, could exist in the solid or liquid state on its surface. These dark patches represent glowing vapours of iron, magnesium, manganese, cobalt, chromium, titanium, and vanadium.

The upheaval in the Sun's surface caused by the outburst of a sunspot extends to the bright calcium vapours which are so abundant in its upper atmosphere. Accordingly, as seen on the background of the Sun's surface, we can observe round the sunspot a large area covered with bright streaks. These are above the general level or boundary of the clouds that make up the Sun's shining surface, or photosphere, and were called by the earlier observers "faculæ," meaning "little torches." These faculæ are few and very bright at the beginning of a solar storm. As the sunspot disturbance grows, and especially when it dies away, the faculæ spread over vast areas.

The disturbance generated by the spot extends to the higher regions of the solar atmosphere, where the chief observed constituent is luminous hydrogen. These regions cannot be observed by the telescope alone, so a supplementary instrument called the spectroscope is required. These hydrogen clouds in the upper atmosphere are whirling round

the vortex caused by the eruption, and are usually being sucked into it.

Below the hydrogen clouds are the calcium clouds, and below these again the vapours of the heavier metals which are flowing out from the vent on to the solar surface. The whole disturbance may be likened in terrestrial atmospheric phenomena to a water-spout, except that in a water-spout the vortex of water particles descends from the clouds to the surface of the sea, while in a sunspot disturbance the whirling is from the surface to the upper atmosphere of the sun.

Leaving this brief survey, I shall conclude by trying to explain the connection of sunspots with Aurora Borealis. Since men began to study the sky, they must have looked with wonder at the brilliant and mysterious exhibitions of the Aurora or Northern Lights. Records of the appearance of these displays have been fairly well kept up, and, as soon as the periodicity of the sunspots was discovered, it was found that there must be some connection between the two—Auroras being frequent in years of many sunspots, and fewer when the spots are few. It was also discovered that whenever there was an Aurora there was a magnetic storm—that is, a disturbance of the earth's magnetic field, accompanied by the flowing of an electric current through the ground. Ordinarily, these magnetic changes can be detected only by special recording instruments, but occasionally, in great magnetic storms, their effect is marked enough to be detected with an ordinary surveyor's compass, shifting the needle about 1 degree.

They are quite different in nature from electrical storms—that is, thunderstorms—and without deli-

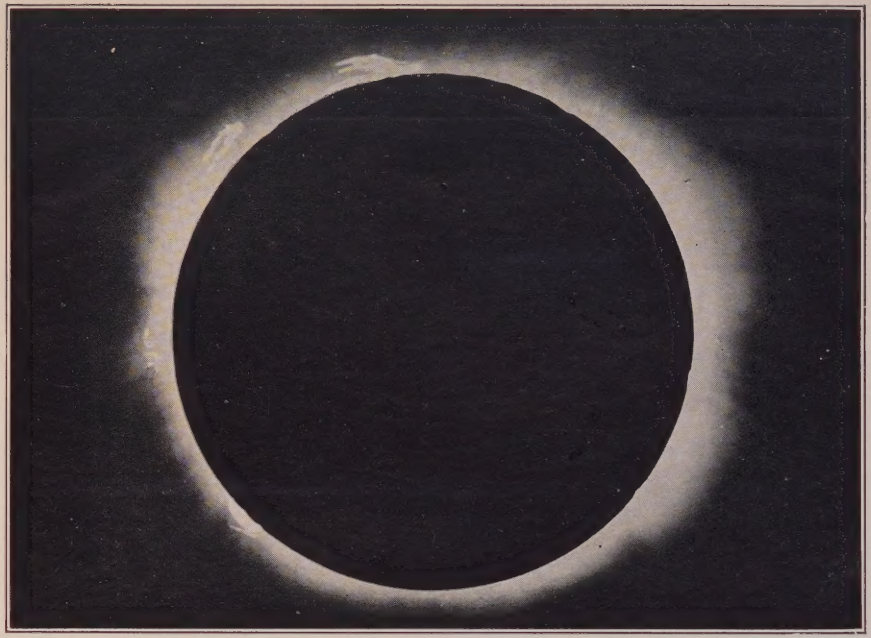
cate magnetic apparatus of some description no one would know they were happening. They often take place when no Aurora is visible, which is not to be wondered at when we consider the fact that we cannot see the Northern Lights by day or in wet weather.

Further study has shown that individual magnetic storms are often associated with individual sunspots occurring when the spot in question is near the centre of the Sun's disc directly facing the earth, and usually when the spot is a little past the centre, as though some influence were sent out which required time to reach the earth. Even very large spots often fail to produce any magnetic disturbances, which indicates that the influence, whatever it be, is not continuously acting.

These facts suggest that the magnetic storms are, in some way, produced by something which is shot out from the sunspots, or from their vicinity, not continuously and in all directions, but at intervals only, and nearly straight away from the Sun. From the time-lag which intervenes between the passage of the spot across the centre of the Sun's disc and the magnetic storm here on the earth it appears that the ejected material takes, on the average, about two days to reach the earth's distance, which means a speed of more than 500 miles per second.

Observations of the Aurora, on the other hand, indicate that it is caused by the bombardment of the earth's atmosphere by small electrified particles or corpuscles which enter the atmosphere from outside, coming down along the lines of the earth's magnetic force, as such corpuscles must do. The auroral streamers occur at varying heights, some coming as low as 45 miles above the earth, and some extending

upwards to 500 miles. Because of these facts it has, for some time, been believed that auroral and magnetic storms are produced by the impact upon the earth of electrically charged particles emanating from the disturbed regions of the Sun.



SOLAR CORONA, TOTAL SOLAR ECLIPSE, JANUARY 1, 1889.

(Photograph by J. M. Schaerberle, Lick Observatory Expedition, Mina Bronces, Chili.)

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TOTAL SOLAR ECLIPSE, AUGUST 30, 1905.

Portion showing large Prominence.

(*Photograph by M. le Comte de la Baume, Pluvinel, Spain.*)

Facing p. 31

CHAPTER IV

ECLIPSE OF THE SUN

In primitive times great terror prevailed among people during a solar eclipse. To see the Sun in midday slowly but surely disappear without apparent cause—for the Moon is quite invisible until its disc begins to cover the Sun's disc—is sufficiently awe-inspiring even to those who understand the reason; and it is easy enough to see how such myths as that of the dragon devouring the Sun came into being. Even in quite modern times a solar eclipse was seriously regarded as a sign and a wonder in heaven; and there is a quaint story concerning a total eclipse which occurred in America while the General Assembly of the Presbyterian Church was in session. Many members were alarmed, some exclaimed that the judgment-day was at hand; but one sturdy member called for candles, that they might proceed with their business, and, if judgment came, be found doing their duty.

The great event of June, 1927, from the astronomical point of view, was the total solar eclipse which occurred on the 29th. Eclipses are quite common things. At least twice every year the Moon passes between the earth and the Sun and nearly in line, to obscure at least some part of the Sun's disc for observers situated somewhere on the earth. Although the Moon is so much smaller than the earth that she cannot hide the Sun even partially from the whole face of the earth at once, she manages to get in the way for any given terrestrial station fifty times or more in a century. Anybody who desires

to do so can see a solar eclipse without leaving home or waiting for many years.

But a total solar eclipse is quite a different thing. To begin with, the Moon must be nearer to us than the average, so that she may look larger than the Sun; or, to put it otherwise, so that her shadow (which tapers to a point at the distance from which the Moon would look as big as the Sun) will reach up to or beyond the earth. This takes place, on the average, rather more than once in two years. But if the point of the shadow scarcely reaches the earth it will be so narrow and will pass over so rapidly that few observations can be made. Allowing for this, and for cases when the shadow path falls in the polar regions or on the ocean, there remains a satisfactory total eclipse every three or four years, an eclipse which can be observed if a person goes far enough to see it.

But an eclipse where the Moon's shadow passes over a densely populated region inhabited by millions of civilized people is a very rare thing indeed, although the intervals between such events are very irregular. The previous total eclipse in the British Isles took place in 1724, and there will not be another until August, 1999, when it will be confined to a portion of the west of Cornwall. During the whole of the following century the only total eclipse of the Sun visible in our country will be about twenty-five minutes before sunset in September of the year 2090, and the phenomenon will be confined to a strip of the south-western counties.

An observer, therefore, has usually to make a long and laborious journey to witness the grandest and most appalling of all sights. He knows the principal phenomena will be over in two or three minutes, and he is wound up to the highest pitch of excite-

ment, not only because the time of observation will be so soon over, but because there are so many things to observe in that time.

The eclipse of June, 1927, happened early in the morning, the Sun being only about 12 degrees above the horizon. For this reason Norway and Sweden were chosen by specially planned eclipse expeditions, because there the Sun was higher and the totality was of slightly longer duration.

At the time of the eclipse the Sun was in the constellation Gemini, and several bright stars were seen, such as Aldebaran, Capella, and Betelgeuse. From the standpoint of the average man, the greatest interest of the sight was its extraordinary character as a spectacle. It was one of the most impressive of natural phenomena.

As the Moon advanced farther and farther across the Sun the light faded, the darkness increased, and, during the last few seconds before totality, the world seemed to darken, like a train entering a tunnel. Observers with a clear view saw the shadow coming with great speed.

On the blue-black sky where the Sun was, appeared the dark circle of the Moon distinctly silhouetted against the silvery and irregular outline of the solar corona. Almost before the watcher had time to take these things in, a brilliant speck of light appeared on the edge of the Moon, and increased to a narrow but dazzling crescent. The sunlight speedily returned and totality was over.

What an Eclipse may mean to Astronomers

The astronomer does not travel half-way round the world merely to see a sight, however wonderful.

His aim is to add to human knowledge. We all know how, in the past, observations at the time of total eclipse have proved that the scarlet prominences which appear here and there along the edge of the eclipsing Moon are really vast clouds of incandescent gas hovering about the Sun and millions of miles beyond the Moon; that the Sun is surrounded by an atmosphere of incandescent gases whose absorption produces the well-known dark lines in the solar spectrum; and that the mysterious corona which extends sometimes to a distance of millions of miles from the Sun is also a true solar envelope, composed mainly of fine particles of dust of some sort, but containing also some self-luminous gas which has not yet been identified on earth, or some known gas in a state not reproducible in terrestrial laboratories.

The usual spectroscopic observations were made of the "flash spectrum" at the moment when the Sun's atmosphere is being hidden behind the advancing edge of the Moon, or coming out again at the other side. (It is so named because of the instantaneous character with which the change takes place.) Just after the Moon had hidden the brilliant disc of the Sun, the Sun's atmosphere was still visible, rising several hundreds of miles, and appearing to the eye as a brilliant steel-white line along the edge of the dark Moon. Photographed through a prism, the light of this atmosphere gave quite a lot of information about the Sun.

Sun's Atmosphere

The spectrum of the glowing gases of the solar atmosphere consists of bright lines matching the dark lines of the ordinary solar spectrum, but some

of these lines are emitted only low down in the atmosphere, close to the photosphere, and appear on photographs as narrow short images; while other lines, which are emitted high up as well as low down, give long and broad crescents—that is, images of the crescent-shaped arc of solar atmosphere which rises beyond the edge of the dark Moon.

From observations made, it is found that the Sun's atmosphere is very extensive. The lower part, in whose spectrum practically all the bright lines are to be found, rises about two hundred miles above the photosphere. In the next few hundred miles most of the lines fade out; but the stronger ones, even of heavy metals like titanium and iron, rise to 800 or 1,000 miles. A few lines go as high as 4,000, while some, belonging to hydrogen, helium, and calcium, rise to 8,000 miles, all around the Sun, forming the chromosphere; and above this, again, to great altitudes in the prominences.

For many years scientists endeavoured to find out some means of measuring directly the earth's motion through the ether which carries the vibrations and the energy of light. Successive experiments failed to detect any such effect. Their failure eventually led to the birth of the now famous theory of Relativity—a subject which is, however, too wide and difficult to go into here.

Einstein's Theory

An extraordinary extension of this theory has been made by the eminent scientist Einstein in 1915, who has attempted to include gravitational phenomena within the scope of his generalizations. His work is intensely mathematical and exceedingly difficult, but

certain consequences of his theory are easily understood. First, the elliptical orbit of any planet, if there were no other planets to disturb it, would not remain quite fixed in position, but its longer axis would slowly swing around the Sun at a speed which can be calculated from Einstein's theory. When applied to the actual planets, this theory gives results too small to measure, except in the case of Mercury. But here it accounts for a large discrepancy between observation and previous gravitational theory which had been known and had perplexed astronomers for a number of years, even to the point of leading several of them to postulate an additional planet, Vulcan, inside the orbit of Mercury. Not merely this, but it accounts for these effects quantitatively, the calculated and observed effects agreeing almost completely. This is a strong argument in favour of Einstein's theory.

But, secondly, his theory also predicts that light originating in the Sun, or any star where the gravitational attraction is very strong, should have a slightly longer wave-length than light emitted by a similar atom on the earth—things happening as though the powerful solar gravitation slowed up the luminous vibration by a small amount.

Thirdly, Einstein's theory predicts that a ray of light passing close to a great gravitating mass like the Sun should be slightly bent inward, as though the Sun attracted the light and deviated it from its rectilinear course. This is, in many ways, the most wonderful of the consequences of the theory. The Sun is the only attracting body within our range which is sufficiently large to produce a perceptible effect. A ray of light which almost grazed its surface would be deflected by nearly two seconds of

arc; while for rays passing at a greater distance the deviation should be inversely proportional to their distance from the Sun's centre.

It is, then, easy to see that a star which we saw by light which had almost grazed the Sun should appear to us to be shifted away from the Sun's centre by the amount just stated. But we can only observe stars close to the Sun at the time of a total eclipse, and one star alone will not be sufficient. We will have several on different sides of the Sun, and some will be nearer than others, so that they appear to be shifted in different directions and by different amounts. Then, by photographing them during totality, and measuring the photographs, it should be possible to determine whether their apparent positions, relative to one another, have been altered as the theory demands. The evidence in favour of the deflection required by the Einstein theory is practically accepted now.

CHAPTER V

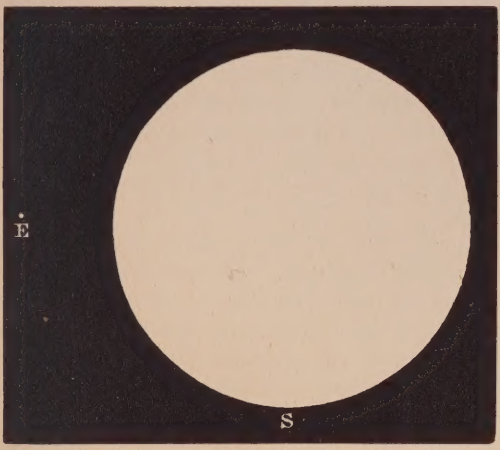
PLANET EARTH

THE subject of this chapter is the planet Earth. To us, this Earth is very great; and yet, compared with other worlds, it is very small indeed. In round figures it has a diameter of 8,000 miles and a circumference of 25,000 miles. Its weight in tons is 6 followed by 21 ciphers. The mean density of the various materials composing the Earth is about five and a half times greater than water. Its shape is spherical. Almost three-fourths of the surface of the Earth is covered with water. The land surface measures about 52 million square miles, and the water surface about 145 million.

It seems probable that the Earth was once at a temperature so high as to be molten. The hot springs, rushing geysers, and the outbreaks of incandescent material, together with frequent earthquakes and flaming volcanoes in various parts of the globe, suggest that there is still great heat in the internal parts of the Earth. However, the older the Earth grows, the cooler does it become. The enthusiasm of youth is not so apparent in old age. This same law is applicable not only to human beings, but to all the suns and worlds in the universe. The Earth is constantly radiating heat into space from its surface, and is therefore cooling down. Consequently, the Earth's crust is probably increasing in thickness, and in a hundred millions of years hence earthquakes may cease.

In this chapter we shall consider two main points: first, the Earth's position as a planet, and, second,

its origin. The Earth travels round the Sun in an elliptical orbit, the longer diameter of which is more than 3 million miles greater than the shorter; and in consequence of this we are much nearer the Sun at midwinter than in midsummer. The mean distance of our globe from the Sun is about 93 million miles. It accomplishes its annual revolution—a journey of nearly 585 million miles—in $365\frac{1}{4}$ days.



Comparative Sizes of Sun and Earth.

While the Earth pursues its annual course, it at the same time rotates upon its axis, or a line of diameter. This axis is not upright or perpendicular to the plane of its orbit, but inclines $23\frac{1}{2}$ degrees from a perpendicular line. It preserves this inclination throughout its annual course, always pointing in the same direction, always keeping parallel with itself. From this simple adjustment a series of

changes and influences result of the greatest importance to our world. By this means the whole round of the seasons is produced, and the duration of light and darkness made to vary, not only at different periods of the year, but also in all the different latitudes of the globe. It is owing to this that during the summer half of the year the days increase in length as we depart from the equator from twelve hours until, at the Pole, there is a continuous day of sunlight for six months; while in the opposite hemisphere there is a similar increase of darkness, until, at the other Pole, there is a night of six months, during which the Sun never appears above the horizon. Had the Earth revolved in a circular orbit, and been set to rotate on a perpendicular axis, we should have known none of these interesting and important vicissitudes.

The civil day of twenty-four hours is not the measure of the Earth's diurnal revolution, but a mean of all the solar days in the year, which are perpetually varying. The exact time in which it rotates upon its axis is 23 hours 56 minutes 4 seconds. This carries its equator round at the rate of more than 1,000 miles an hour.

But this is not all the travelling we do in the course of the year. The Sun and all its family of worlds are travelling through space towards that part of the heavens marked by the constellation Lyra. The Solar System is making the rapid progress of over 1 million miles per day; but so great is the distance of the stars that, although the Solar System accomplishes in one year a journey of 380 million miles, no visible change can be observed in the constellation toward which we are bound in a much longer period.

One of the most interesting questions in astronomy

is, how did the Earth and the other planets come into existence? The modern explanation is, that they were ejected from the Sun during enormous eruptions caused by the close approach of a gigantic star, and set moving sideways in orbits by the attraction of the star as it receded. It is generally supposed that the stranger passed at an ordinary speed only several millions of miles from the Sun's surface, and that that extraordinary event occurred several thousand millions of years ago.

The effect on the Sun was most terrific. The gravitational pull of the passing stranger raised tremendous tides on the mass of the Sun, just as the gravitational pull of the Moon and the Sun raises tides in the oceans of the Earth. It is probable that the tide raised on the side of the Sun away from the intruding star was comparatively small; but, on the near side, a huge wave of material was raised, with the result that it formed a great mass of white-hot gas, which spread for millions of miles out into space. It stretched out so far that it became detached, and the pull of the giant star, as it passed away, set the gas whirling round the Sun. It is supposed that this gas cooled and broke up into the planets, as a cloud of steam condenses into separate drops of water, and that these planets continued to move round the central mass—the Sun—from which they were created. The excessive stream of white-hot matter drawn out of the Sun by the passing of this star would be similar to a cigar in shape—that is, thin at each end and thick in the centre. Most of the material would be in the thicker portion, and we may well understand that the planets formed in this part would be larger than those formed nearer the Sun or at a great distance from it. In support of

this supposition, it is a well-known fact that the giant planets Jupiter and Saturn are situated nearly in the central part of the Planetary System. It is also worthy of notice that Mercury, the smallest planet, is the one nearest the Sun, and accords well with this theory, for it seems that Mercury was created near the inner end of the appendage; while Pluto, the planet farthest from the Sun, was produced at the end of the stream of glowing material pulled out from the Sun. Further, in addition to those nine great masses, a large number of small ones remained in motion about the Sun, such as the satellites, asteroids, comets, meteors, and the dust and gas that are very loosely dispersed throughout the Solar System. The time at which all this happened was probably about 4,000 million years ago. This indicates that the Sun was a "going concern" at that time, and must therefore be much older than this.

Since then the paths of the planets around the Sun, which were originally of considerable eccentricity, have become nearly circular. The gaseous surface quickly liquefied and, in the case of the inferior planets, solid crusts were developed. Since the great cataclysm, the Sun has never been disturbed further. It settled down, and, so we infer from a study of fossils in terrestrial rocks, the Sun has been constantly pouring sunshine into space at a regular rate.

Since the eruptive birth of the planets, they have cooled as a result of the radiation of their heat into surrounding space. Their gaseous surfaces have liquefied, and the liquids, for the most part, have frozen. On the earth, however, large bodies of the hydrogen-oxygen combination called water remain in a liquid form in oceans and lakes; but the liquid

iron, calcium, magnesium, silicon, zinc, gold, silver, and other elements, have all condensed into the solid form of earth and rocks. On the most distant planets, where the Sun's heat is not so powerful, the water is probably frozen. The theory of the origin of the planets that I have just outlined is called the Tidal Evolution Hypothesis. The scientists mainly responsible for its present form are Sir James Jeans and Dr. Jeffreys of England and Professors Chamberlin and Moulton of America. There are many other problems of origin closely connected with the origin of the Earth and planets: for instance, the origin of the Moon, which is probably an offshoot from the Earth, the origin of the satellites of the giant planets, the origin of comets, and the origin of the Sun from which all these small secondary bodies have been formed.

CHAPTER VI

THE MOON

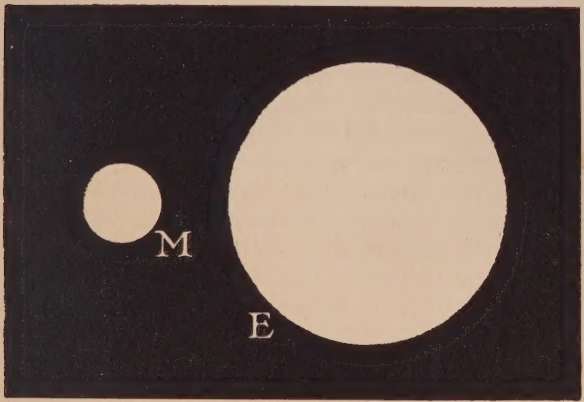
THE Moon is our nearest neighbour in the heavens, and is, in fact, an appendage of our world. In herself she is a dark body like our earth. She shines by borrowed light, and becomes visible simply by the rays of the Sun falling upon her disc. The Sun always illumines one-half of her surface; but that enlightened side is so situated at different points of her orbit that we see only a less or greater part of it; and hence arises her ever-varying aspect.

The Moon revolves round the earth in 27 days 7 hours 43 minutes 11·5 seconds; but while she has been accomplishing it, the earth has been moving along on its yearly path, at the rate of 66,000 miles an hour; and, in order to overtake it, so as to appear exactly at the same point in the heavens as she did at the beginning of her circuit, she has to travel on for 2 days 5 hours 1 minute longer; so that what is called a lunar month, or the time from one new Moon to another, is 29 days 12 hours 44 minutes 2·8 seconds.

While the Moon thus revolves round the earth, she also rotates on her axis in precisely the same period, and by this arrangement she keeps the same side of her sphere always towards the earth. This may be easily explained. Let a lamp standing in the centre of a circular table represent the earth, and let a person move once round the table, always directly facing the lamp, and he will find that, in going round, he has faced every point of the com-

pass, or made a complete rotation on his axis, while his face, like the Moon's, has been all the time towards the lamp. Thus, the Moon is found to have a triple motion, besides certain other oscillations of too abstruse a nature to be introduced here.

Moving in an elliptical orbit, like all the other heavenly bodies, the Moon is sometimes nearer and sometimes farther. Her mean distance from the



Comparative Sizes of Moon and Earth. (The distance apart on this scale should, of course, be much greater than shown—in fact about 4 feet.)

earth is 238,793 miles, while her diameter is 2,160 miles.

A few words may be said regarding the varying altitudes of the Moon and her different altitudes when new. Her rising in the east and setting in the west is obviously the result of the earth rotating in the opposite direction; but if we put aside the effect of our own rotation by observing at the same hour every day or night, or if we allow for the rotation

when observing at other hours, we shall see that the Moon circles round the earth in the same direction as the earth rotates, and that, commencing from new Moon, she leaves the neighbourhood of the Sun on its eastern side and travels constantly in the same direction until passing her full at 180 degrees from it. She still continues until she reaches its vicinity on its western side, to pass it and become a new Moon once more. The Moon's orbit not being in the same plane as the Sun's apparent orbit, but inclined 5 degrees to it, the Moon may pass 5 degrees north or south of it at new Moon, and she may also be as much above or below the ecliptic at any other part of her path. As she completes her circuit from the Sun to the Sun again in about 29½ days, she occupies her highest and lowest altitudes for the month, and every intermediate altitude twice each month; and her meridian altitude in every position is dependent upon the position of the Sun in its orbit at the time, and the Moon's angular distance from it. When she is new she is near the Sun, and consequently is nearly at the same altitude; and when full she is opposite and is nearly as much above the equator as the Sun is below it, or the reverse. Thus, in summer the new Moon is high and the full Moon is low; while the quarters are at medium height. In winter the new Moon is low and the full Moon high, the quarters being again as in summer. In March the new Moon is at medium height, as is also the full, and the first quarter is high and the third quarter low. In September, again, the new and full Moons are at medium elevation, but the first quarter is low and the third quarter high.

The Moon presents us with an interesting class of phenomena in the eclipses which she sometimes

occasions to the Sun, and sometimes undergoes herself. An eclipse of the Sun is caused by the Moon in her revolution round the earth coming between us and the Sun, and, being a dark globe, she appears as a black spot on the Sun's surface, covering a less or greater portion, or even, in some conjunctures, the whole of its disc. An eclipse of the Sun can take place only at the time of the new Moon. The shadow of the Moon which, on such occasions, falls upon the earth, covers only a small portion of its surface, not being at any time more than 180 miles in diameter. This shadow travels the surface of our sphere at the rate of thousands of miles an hour, so that the Sun is never totally obscured, at any particular point, for more than about seven minutes.

An eclipse of the Moon is produced by the interposition of the earth between her and the Sun. The earth, being a dark body and enlightened by the Sun, casts a shadow in the form of a cone on the opposite side, which reaches to the distance of 860,000 miles, or three and a half times the distance of the Moon's orbit; and when the Moon happens to pass through this shadow, she is deprived of the Sun's light and eclipsed. This can take place only at the full Moon, and as this shadow is about 6,000 miles broad at the distance of the Moon, her passage through it, when central, occupies from beginning to end about 3 hours 45 minutes. All eclipses both of the Sun and Moon recur within a period of 18 years and 10 days.

Eclipses have served to establish the dates of many events recorded in ancient history. The occurrence and character of an eclipse, together with the locality at which it was observed in connection with any memorable event of antiquity, being given,

the astronomer, by calculating backwards, can read off by the timepieces of the universe the exact time when the event took place. The celebrated eclipse mentioned by Herodotus, which, by its ominous appearance, caused the suspension of the battle between the Medes and Lydians, followed by a treaty of peace, has been ascertained to have occurred in the year 585 B.C.; and not only so, but the course of the Moon's shadow over the earth's surface, being also traced by the same calculation, determined the field of the impending conflict to have been at the mouth of the river Halys. Another eclipse mentioned by Thucydides as having happened on the afternoon of a summer's day, in the first year of the Peloponnesian War, is found to have occurred on August 3, 413 B.C., and to have passed over the city of Athens. Xenophon relates that during the siege of Larissa an eclipse of the Sun took place, which produced a panic among its Median defenders, of which the Persians took advantage and captured the city; and astronomical calculation has fixed the event on August 15, 310 B.C., and proved that the shadow, being on this occasion only twenty-five miles in diameter, passed centrally over the place.

In the British Museum are two blocks of stone which were exhumed from the ruins of Nineveh. One of them contained a list of the kings of Assyria and the other a list of dates. On the two stones being put together, it was found that they were complementary parts of the same stone, fitting precisely into each other, and giving a complete record of the Assyrian empire for a period of 243 years. Among the facts recorded on these stones is an eclipse of the Sun, which is distinctly noted. It was found by astronomical calculations that the eclipse occurred on

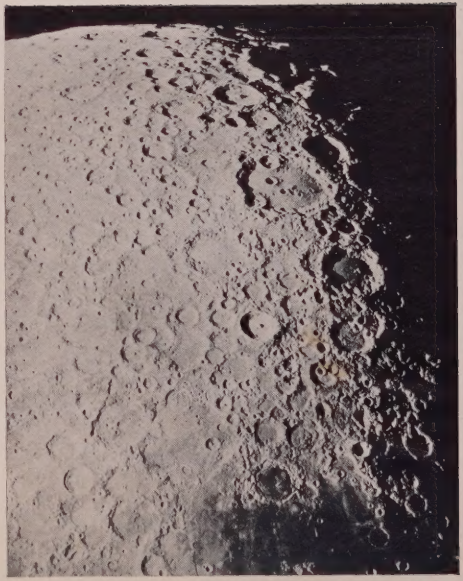
PORTION OF MOON, SHOWING COPERNICUS AND MARE IMBRIUM.

(*Photograph by G. E. Hale, October* 5, 1909.)

Facing p. 48

MOON: MARE IMBRIUM.

(Mount Wilson Observatory, California.)



MOON: MARE NUBIUM.

(Yerkes Observatory.)

Facing p. 49

June 15, 763 B.C. Thus, the Sun and Moon point out to us the places and read to us the dates of events that transpired in the world hundreds and thousands of years ago.

Let us now enquire into the Moon's physical condition as suitable to the sustenance of life. The mass of the Moon is so much smaller than that of the earth that the force of gravity at its surface is too weak to retain an atmosphere anything like the density of our own. Gravity at the Moon's surface is one-sixth that of the earth—that is, 6 pounds on the earth would weigh 1 pound on the Moon. One man could carry six men on his back as easily as he could carry one here. A volcano on the earth throwing lava one mile would hurl it six miles on the Moon. Owing to the Moon's small size and weak attraction, the air has escaped into space. If any atmosphere exists it is not more than one-thousandth part of the density of that around us. We cannot suppose that so small a quantity of air could be of any benefit in sustaining life. The rays of light from stars when the Moon passes them suffer no change until they are instantly cut off by the solid edge of the Moon. There are no clouds and no water. Air and water have apparently all been absorbed into the solid crust of our satellite. Without air and water no vegetation can exist, and hence no life.

The proof of the absence of life is yet stronger when we consider the results of actual telescopic observation. An object such as an ordinary city block could be detected on the Moon. If anything like vegetation were present on her surface, we should see the changes which it would undergo in the course of a month, during one portion of which

it would be exposed to the rays of unclouded Sun, and during another to the intense cold of space, but the telescope reveals nothing except volcanic ashes.

The Sun's rays beat down fiercely upon the surface, unrestrained by the blanket of air and vapour which on earth both tempers and retains the heat. But the absence of this blanket allows the Moon's heat to be radiated into space. The temperature at lunar night is intensely cold—about 150 Centigrade degrees below freezing-point. On the other hand, the lunar midday temperature is very great, reaching a greater heat than that of boiling water on the earth; in other words, about as high above freezing as it is below it at night.

We not only observe the Moon with the telescope, but we get still more definite information by photography. The whole visible surface has been often photographed under the best conditions; but no change has taken place. Photographs show no difference of structure or shade which could be attributed to cities or other works of man. To all appearance the whole surface is as totally devoid of life as the lava newly thrown from Vesuvius.

CHAPTER VII

"THE MAN IN THE MOON"

THE irregular markings on the face of the Moon attracted the attention of mankind many hundreds of years before the invention of the telescope, and appear from the earliest times to have been regarded as forming the features of an imaginary face. Writers of antiquity have made several references to this imagined face. In some cases the features recognized were those of a man, in others of a woman. "The Man in the Moon" of later days seems to have been usually pictured as a man carrying a bundle of sticks on his back and accompanied by a dog. But those who have not heard of the sticks and dog generally imagine a face only in the full Moon.

The dark parts which show the eyes, nose, and mouth are generally supposed to be of material resembling lava. The name "Seas" was given to them by Galileo and is still retained, though it has been known for long that they are quite dry.

Other markings of interest are the mountains, some of which are 23,000 feet in height. The most magnificent mountain ranges are the Alps and the Apennines, named after those on our earth. Among the former are hundreds of peaks, one of which rises to a height of 12,000 feet. The Apennines rise gradually from a comparatively level surface to a height of 20,000 feet. No fewer than 3,000 high peaks are visible to earth's astronomers. In addition to the mountain ranges there are 32,000 craters, many of which are from 30 to 60 miles in diameter.

These craters seem to present characteristics of volcanic eruption in a very remarkable degree. On some of them it would seem that the lava has risen almost to the point of overflowing, suggesting the great heat that once operated there. These craters are full of interesting details, but we cannot stop to investigate. One of the best examples we find of volcanic activity is the immense crater Plato, whose diameter is 70 miles. Its border, varying in height from 3,000 to 4,000 feet above the interior, is crowned by several lofty peaks, the highest being 7,400 feet. Three on the west are respectively 5,000, 6,000 and 7,000 feet in altitude above the floor.

Four craters are specially interesting, probably as the result of a vast discharge of molten matter ejected at the focus or centre of disruption of an extensively upheaved portion of the lunar crust. These are Tycho, Copernicus, Aristarchus, and Kepler.

Tycho is 54 miles in diameter and upwards of 16,000 feet deep. The central cone is 5,000 feet in height. The outer slope of Tycho includes craters, crater-pits, shallow valleys—in short, nearly all sorts of lunar feature are represented. This is one of the most prominent of the lunar craters, because it occupies the great focus of disruption, from whence diverge those remarkable bright streaks, stretching over 1,000 miles of the Moon's surface.

Copernicus is one of the grandest and most instructive of the lunar craters. Its diameter—55 miles—is exceeded by others, yet, taken as a whole, it forms one of the most impressive and interesting objects of its class. The walls are surmounted by many peaks, one of which, on the west, stands 11,000

MOON: TYCHO.

(Lick Observatory, California.)

Facing p. 52

MOON: COPERNICUS.

(Mount Wilson Observatory, California.)

Facing p. 53

feet above the floor, and a second on the opposite side is nearly as high.

Aristarchus and Herodotus are conspicuously situated in the north-east quarter of the Moon's disc. The former has a diameter of 29 miles, and is the most brilliant on the Moon. Its border rises 2,000 feet above the outer surface on the west, but towers to 7,500 feet above the glistening floor. Its terraced walls are conspicuous, while, on the south, they are particularly prominent. The Moon's long day on this side of her globe is a fortnight, during which time the dazzling glare of the Sun's rays has been beating down on these shelterless plains, which, for want of a proper atmosphere, cannot retain long the smallest degree of Sun heat.

The ring-plain of Kepler is 22 miles in diameter. A peak on the east attains an altitude of 10,000 feet above the surface. The wall is much terraced, especially the outer slope on the west. Kepler is the centre of one of the most extended systems of bright streaks on the Moon's visible surface.

Two theories are held regarding the origin of the lunar craters. The first theory is that they are the result of volcano activity on the Moon, just as terrestrial volcanoes are one of the results of volcanic activity on the earth. The second theory is that they are the result of collisions of meteoric bodies with the Moon.

Many plutonic forces have been prominent in shaping the Moon's destiny. The lunar mountain ranges are, in several respects, comparable with terrestrial ranges. Many of the lunar seas are supposed to be overflowed areas, just as great terrestrial areas were overflowed by molten lava. The seas contain the remnants of many craters, in which only

the summits of the crater rims continue unsubmerged.

Those in favour of the meteoric theory point out that many of the craters have central peaks varying in height from 3,000 to 7,000 feet. These peaks are said to be due to reactions from the collisions. While it is admitted that the number of these peaks is great, they are certainly not common. Most of the lunar craters contain no central peaks. Professor William H. Pickering states that central peaks seldom happen in craters less than four miles in diameter.

Another fact worthy of notice is that the existing peaks in many craters are not central. In a large number there are two or more peaks near the centre, but no central one. Some astronomers have observed high volcanic cones on the Moon with small crater openings on the top. Pickering has noticed a few craterlets at the summits of the central peaks in several craters. He states that "outside of the craters there are many examples of high peaks which carry small minute summit craters, and are thus analogous to terrestrial volcanoes." He says, further, that "in most cases these summit craterlets are less than a mile in diameter." The fact that craterlets exist in the summits of central crater peaks is quite in accordance with the theory of the volcanic upbuilding of those peaks.

Supporters of the impact theory of crater origins on the Moon argue that the floors of the craters are not only far below the level of the tops of the crater rims, but are often very considerably below the level of the surrounding plains. They hold that the terrific impacts of meteorites excavated the resulting crater interiors to the huge depths observed, the

materials having been cast out upon the adjacent areas. Could such a tremendous action, capable of excavating a crater 50 miles in diameter in two or three seconds of time, avoid liquefying the crater interior? If a central peak were hurled up as a reaction effect, it would be drawn down at once by lunar gravitation. The interior wall of the rim could not possibly remain so steep as it is seen to be, nor could the interior walls of crater rims be terraced so distinctly as astronomers observe this effect in many craters if the impacts had emptied the crater bottoms down to their present low levels. A more probable description of the origin of a lunar crater and its central peak is the popular one held by those who look with favour upon the theory of volcanic origins. The volcanic theory has been supported by many eminent astronomers, including Nasmyth, Carpenter, Herschel, Arrhenius, Ball, and Campbell.

And now a few words regarding the bright streamers which radiate from the craters Kepler, Tycho, Copernicus, Aristarchus, and others. How is their presence to be explained? We may discard the opinion that these luminous streaks are due to the filling up of cracks radiating from the craters by materials of lighter colour from the Moon's interior. The streamers from several craters are singularly straight; while in some they run indifferently over level plains, crater bottoms, crater walls, and mountain structure. One explanation which is given regarding them is, that they are volcanic projectile discharges from craters. Several of these streamers, such as those extending out from Tycho, are hundreds of miles in length. The brighter materials responsible for the streamers perhaps left

their crater origins as projectiles with a velocity strong enough to carry them over a large surrounding area of the Moon, where they are now seen. We have always to remember that the force of gravity at the lunar surface has only one-sixth its value at the surface of the earth, and that the motions of the particles hurled from the craters would meet with no atmospheric resistance. Dust particles of low density would move as far as heavy pieces of high density. It is perhaps possible that a volcanic eruption in the crater Tycho could discharge liquid or dust particles with a velocity sufficient to explain the distribution which we observe. As the walls, the terraces, and central peak of Tycho are what would be expected from a volcanic origin of the crater, we may consider possible the volcanic eruption theory of the uncommon system of streamers which centre at that point. Tycho is, therefore, the representation of latest volcanic activity in the area which it occupies. The streamers which radiate from Copernicus are not so straight as those from Tycho. Some streamer materials may have reached their present destination on ejection lines lying above the lunar surface, while other materials may have followed the usual processes of volcanic flow.

There is every reason to believe that the main surface features are the ordinary products to be expected from evolutionary processes purely plutonic; that we may, on this theory, assign to many surface features their relative ages; and that, while some small craters may possibly be the result of meteoric collision, the evidence for the volcanic origin of the larger craters is very strong indeed.

CHAPTER VIII

THE ZODIACAL LIGHT

Just after sunset in the western sky in the early months of spring, on clear evenings when there is no moon, we cannot fail to notice a hazy cone of soft light stretching from the horizon nearly to the zenith, along the plane of the ecliptic. In colour it is a very pale apple-green. At times a faint yellowish tinge seems to overspread the nebulous light, and again, on some nights, it is so faint that no colour can be discerned, and it is only by glancing at it with averted gaze that we can discover the presence of any glow whatever.

Its usual shape, if it might be said to have any, is that of a wedge of indefinite and hazy outline, with its base at the horizon, and its apex gradually fading out at about 90 degrees from the position of the Sun below the horizon.

The name "Zodiacal light" was given to the phenomenon by Cassini in 1653, and it was described by him as a "flat luminous ring encircling the Sun nearly in the plane of the ecliptic."

While it is a rare occasion when one is able to trace the light to more than 90 degrees from the Sun in our latitude, in the Tropics, under favourable conditions of observation, the light has been reported as extending completely across the heavens, and where such an observation is possible there is a conspicuous brightening of a spot directly opposite to the Sun's position below the horizon.

In Germany this light has been given the name

"Counter-glow." Since the Zodiacal light extends on both sides of the Sun, and may be seen in autumn just before daybreak as well as in the spring, some investigators have supposed the Zodiacal light to be a very extended outer envelope of the Sun, enclosing the corona, and extending very far out into space.

Kepler adhered to this theory, but Laplace showed that the atmosphere of the Sun could not extend to anything like the distance from the Sun that is attained by the Zodiacal light. The outlines of the glow are everywhere ill-defined, so that no definite boundary can be set to the extent of the Zodiacal light. The phenomenon is produced at its centre, called the axis of the light. Along this axis the brilliancy continuously increases as the Sun is approached. The deviation from the plane of the ecliptic is small, but plainly discernible, and amounts to about 5 or 8 degrees. The conditions of visibility will, of course, be best when the ecliptic and consequently the axis of the light are most nearly perpendicular to the horizon. As the angle between the horizon and the central line or axis of the glow becomes acute, the light grows fainter, due to atmospheric absorption, and is scarcely perceptible when the angle is less than 45 degrees.

At the close of the evening twilight in the spring, the angle is largest about three weeks from the Vernal Equinox; consequently the month of March is especially good for the observation of this phenomenon. The fact that the base of the triangular-shaped light area is nearest the Sun seems to lead to the inference that the light surrounds the Sun.

One source of error which may occur to the observer is the question as to whether the light observed is really the Zodiacal light, or whether it

may not be the faint illumination arising from the reflection of light from the rare upper atmosphere, which is known from the appearance of meteorites to extend for some hundreds of miles from the surface of the earth. Separation of this effect from the true Zodiacal band may seem to offer some difficulty, but as the real light is studied it is found that after the ordinary twilight has ceased in the evening the northerly extension of the Zodiacal light works around more and more to the north as time goes on, and finally, at about midnight, merges into the light of the sky. The "counter-glow" is described as being well seen only when the Sun is less than 20 degrees below the horizon, and just after twilight has set in.

A theory was deduced, about sixty or seventy years ago, of a ring of finely divided matter extending beyond the orbit of the earth. It is supposed that these minute particles are thrown out from the corona of the Sun, or from the Sun's equatorial regions.

Another theory advanced was that these meteorites were in a vast swarm filling the space between the earth and the Sun. In this connection it may be mentioned that the maintenance of the Sun's heat has been attributed by some to be due to the falling of these meteorites into the Sun's mass and the loss in radiation thus made up. It is certain now that these bodies, if they exist at all, have nothing to do with the production of Zodiacal light.

The only hope which we now seem to have of solving the question is centred on the polariscope and spectroscope. The evidence provided even by these powerful aids, however, is not always in accordance. In 1867 Dr. Ångström was able to detect the auroral line, and from this he concluded that

the Zodiacal light was composed of the same material as is found in the Aurora, in the solar corona, and probably all through space. It has been found that the spectrum of the light is practically continuous, and that, therefore, the glow is essentially reflected sunlight.

A valuable contribution regarding the light of the sky was published some years ago by a Dutch astronomer, Dr. Van Rhijn. He has shown that most of the luminosity of the sky near the North Pole is due to an extension of the Zodiacal and Auroral light over the entire sky. It is known that the brightness in the sky along the ecliptic near the Sun is caused by the reflection of sunlight by the fine dust scattered through interplanetary space, and most numerous near the Sun. His work shows that this cloud of "cosmic dust" must stretch far beyond the orbit of the earth, and that no portion of the sky is free from this reflected light. According to his calculations, the intensity of this reflected sunlight, even near the poles of the ecliptic, is much greater than the light of the stars themselves, except in the Milky Way. Along the ecliptic the reflected light is nearly twice as strong, while at a distance of 40 degrees from the Sun it is brighter than the Milky Way.

After allowance is made for this Zodiacal light and for the light of the stars, it is found that there is still another source of light in the sky which gives an illumination that is faintest overhead, but that increases gradually toward the horizon. This is explained as true "earth light" arising from a permanent Aurora in the upper atmosphere. It is known that most of the light of the Aurora is produced in a layer only a few miles in thickness and about sixty miles above the surface of the earth.

The more obliquely we observe this layer, the greater is the effective thickness and the brighter the Auroral light. The intensity of this Auroral light changes irregularly from night to night.

Summarizing the conclusions of the Dutch astronomer, it seems that only about one-half of the light of the sky even in the Milky Way comes from the stars, and that in regions far from the Galaxy the stars furnish only a small fraction of the whole. Of the remainder, the much larger portion is caused by sunlight reflected by meteoric particles or fine dust in interplanetary space, while possibly one-fifth is due to the earth's atmosphere from a faint permanent aurora. The subject is worthy of a great deal of further investigation, and, apart from the purely scientific features, the phenomenon is extremely interesting to watch.

CHAPTER IX

RACE OF THE PLANETS ROUND THE SUN

Sometimes casual observers see Venus as a very bright object in the evening sky; but after a time they observe that she has become a morning star, and wonder how such a thing can happen. Again, at intervals of two years and two months they notice a brilliant red star, which they suppose has appeared suddenly in the sky, and which, after shining with increasing and decreasing light for some months, they miss, and cannot conceive how it came and how it has disappeared.

With regard to Jupiter and Saturn less difficulty arises, but, like Venus and Mars, they vary considerably in their altitudes when due south, and consequently in their length of path above the horizon in their daily motion from east to west, owing to the earth's rotation. The earth turns round every day, and also travels about 1 degree in its orbit towards the east as seen at midnight, thus apparently changing the position of the stars with reference to the Sun about 1 degree per day towards the west. A star that rises due east will set due west, and in its course mark out the plane of the earth's rotation. It rises and sets every day about four minutes earlier, owing to the earth's motion in its orbit. If any particular star of about 40 degrees elevation when due south is observed, and its position fixed by a line of adjustment with some terrestrial object, it will be found the following night nearly 1 degree farther west, and so on for each

succeeding night throughout the whole year, so that the stars that were due south at any date of one year will be found nearly due south again at that date in succeeding years. Thus, the annual motion of the earth becomes manifest to the eye.

Before we follow briefly the apparent motions of the four planets, let us begin by considering the various positions of an inferior planet, as seen from the earth, during the course of its annual journeys round the Sun. To these positions technical names are given. When the inferior planet is on the far side of the Sun from us, it is said to be in Superior Conjunction. When it has drawn as far as it can to the left hand, and is then as east as possible of the Sun, it is said to be at its Greatest Eastern Elongation. When it is passing nearest to us, it is said to be in Inferior Conjunction. When it has drawn as far as it can to the right hand, it is spoken of as being at its Greatest Western Elongation.

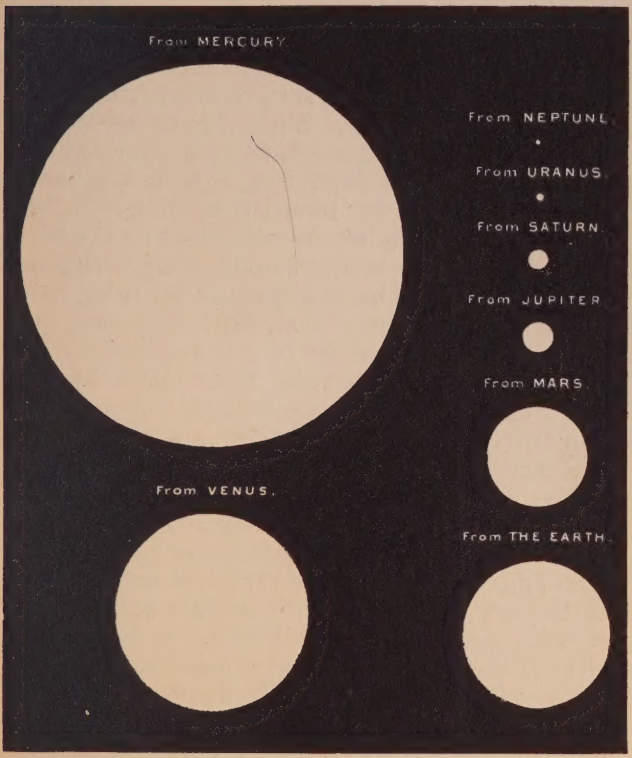
The inferior planets exhibit various phases comparable to the waxing and waning of the Moon. Superior Conjunction is similar to full Moon, and Inferior Conjunction to new Moon; while the eastern and western elongations may be compared respectively to the Moon's first and last quarters.

An inferior planet is called an evening star when it is at its eastern elongation, for, being then on the eastern side, it will set after the Sun sets. Similarly, when such a planet is at its western elongation, it will go in advance of the Sun, and will rise above the eastern horizon before the Sun rises, receiving the designation morning star.

If we commence our examination of the motions of Venus when she is on the opposite side of the Sun, and suppose that Venus and the earth

are two cyclists travelling upon concentric paths with the Sun in the centre, and that Venus travels on a track roughly about two-thirds the diameter of that of the earth, and is the more rapid rider, we shall easily follow her motions with regard to the Sun. At first Venus is hidden by the Sun's rays on its other side from us, but, travelling faster in the same direction as the slower earth, she gains and draws away from the Sun towards the east. It will be about two months before she is visible to the naked eye to attract attention. She continues to travel farther east of the Sun and to increase in brightness, until, in 218 days, she has reached her greatest distance east. About this time she varies very little in her apparent distance from the Sun, because she is coming round the curve, as a cyclist would, almost directly towards the earth. But she continues to increase in brightness for another 35 days, while slowly approaching the Sun at first. Then her velocity appears to increase rapidly, and she closes up to the Sun, quickly losing light in 36 days more. Then passing between us and the Sun, as the cyclist would, she commences to open out west of it, and becomes a morning star, attaining her greatest brilliancy west in another 36 days, and in another 35 days her greatest western elongation, when she again falls back towards the Sun in the more distant part of her orbit, until she passes nearly behind it, to begin once more the same round of duties. As in the distant part of her orbit she travels apparently slowly, owing to her distance, and her course from the other side of the Sun to her point of greatest brightness is much longer than it is from that point to the side of the Sun, where from her proximity she seems to move rapidly, the cause of

her apparently sudden disappearance is seen. She requires 253 days to move from superior conjunction



Comparative Sizes of Sun as seen from Planets.

to greatest brightness, and only 36 days from greatest brightness to inferior conjunction. As her brightness during these 36 days speedily decreases, and she

also swiftly approaches the Sun, she is seen conspicuously for just a portion of the 36 days. She, of course, also makes a sudden appearance as a morning star, and in 253 days after greatest brightness again passes behind the Sun.

We may also study the movements of Venus at the time of her starting from her greatest western elongation as a morning star. She is then to the right of the Sun, and her motion relative to it resolves itself into a long and slow swing from right to left, and a short and rapid swing from left to right. In her swing from right to left she passes behind the Sun, and is invisible for several months, disappearing on its right to reappear on its left, and in her swing from left to right, requiring a much shorter time, she passes between us and the Sun, and is invisible for only a short time. The swing from right to left and then from left to right requires 436 and 142 days respectively. Accordingly, there are about nineteen months from the time she is at any one point relative to the Sun and the earth until she is at that point again. Thus, her succession of appearances as an evening star, or as a morning star, are at intervals of nineteen months, and happen at various times of the year. On this depends her altitude in the sky at these periods. Her path being nearly in the plane of that of the earth, and at her elongations she being only 47 degrees from the Sun on either side, and the Sun being highest in June and lowest in December, it follows that the greatest altitudes of Venus will be when her evening elongations occur early in May and her morning ones in August, and her lowest positions will be when she is our evening star in November and a morning star in February.

In the case of Mars, the earth occupies the inner path and Mars the outer, and it is the earth which moves the faster and gains on Mars. If the overpowering brilliancy of the Sun did not render Mars invisible when near it in the sky, we should be able to watch the whole track. It travels round the Sun at such a speed that from the time when it is in the opposite part of the sky to the Sun until it reaches it again is, on the average, 780 days, or nearly 26 months. If Mars had no orbital motion, the earth's motion would bring it in opposition every 365 days, but as Mars has moved on in the same direction during the 365 days, the earth has to follow and complete more than another round before Mars is again in opposition. Commencing from the point when Mars is hidden by the Sun, it appears to leave the Sun on its western side as the earth gains upon it. It, accordingly, appears shortly before sunrise, and, not being very brilliant, is probably not seen until considerably to the right of the Sun. It still recedes from the right of the Sun, until the earth, in its more rapid motion, passes between them, and Mars is due south at midnight and at its greatest brilliancy. After that, still going to the right, it commences to approach the Sun in the evening sky, its brilliancy decreasing until it is lost in the solar rays, and it passes behind the Sun to appear again as a morning star. The path of Mars, then, relative to the Sun, is a general progress from east to west, and appears contrary to its real motion in its orbit, which is always from west to east, and the apparent motion is the result of our own swift motion in the same direction as the real motion of Mars.

Mars varies considerably in brilliance at the

various dates of its appearing on the meridian at midnight, because its orbit is not everywhere equally distant from that of the earth, but is so situated that the point where the two orbits are nearest is the point where the earth is about August 27, when Mars may be only 35 million miles distant, and the point of the orbits where they are most separated corresponds to where the earth is at the end of February, when Mars will be 62 million miles away, and less than one-third as bright an object as in August. As the oppositions take place at intervals of two years and a fraction, they happen at many different points of the two orbits, and so the planet varies very much in splendour when in opposition.

As to Jupiter and Saturn, their apparent paths come into opposition at intervals of little more than a year, and their motion from east to west during their time of visibility is clearly the result of the earth's motion in its orbit. The fraction over a year between oppositions is due to the two planets having moved so much forward in their orbits that the earth requires 34 days in the case of Jupiter and 13 days in the case of Saturn to catch them up.

A word in closing with regard to their varying altitudes at opposition. As these planets travel nearly in the same plane as the earth, which is also the plane of the Sun's apparent path, and this is elevated high at midday in summer and is low at midnight, while in winter it is low at midday and high at midnight, and the planets must be in the opposite part of the sky to the Sun when in opposition, it is obvious that the nearer the midnight passage is to the midsummer, the lower the planet will be in the heavens; while the nearer the midnight opposition is to midwinter, the greater the altitude of the planet;

in other words, in summer the planets are low in the sky at night, while in winter they are high, just contrary to the Sun, because they are in the opposite part of the sky, and their spring or autumn oppositions are at medium elevation.

CHAPTER X

VENUS

The planet Venus is the second in order from the Sun, her orbit lying between that of Mercury and the earth. To the naked eye she is the most brilliant and beautiful object in the heavens. When she rises before the Sun she is a morning star, and when after, she is an evening star for about the same length of time. This planet, like Mercury, exhibits all the phases of the Moon, at one time appearing as a most beautiful crescent, then a half-moon, then gibbous or bulging, and then gradually becoming full. After this she passes through a series of changes of an opposite character, gradually waning from the full to the gibbous, then the half-form, then to the same lovely crescent, when it is entirely lost to view in the superior brilliancy of the Sun, which by this time it has apparently approached. When Venus is at her brightest she appears $5\frac{1}{2}$ times as bright as Jupiter, 10 times as bright as Sirius, and 300 times as bright as the Pole star. The average star-gazer would probably be surprised to learn that the difference between Venus and Jupiter was so great, and would have been inclined to guess that Jupiter was more than half-way between Sirius and Venus in brightness, but there can be no doubt of the truth of the statement just made, which rests upon the results of a long series of careful observations. Evidence of the far greater brightness of the nearer of the two planets is afforded by the attempt to see them by daylight. Jupiter, it is true, can be

seen a little before sunset in clear weather if one knows where to look for it, but it is faint and difficult to find, and can only be seen when the Sun is low; but Venus, under the same circumstances, is a conspicuous object, and she can be seen without optical aid at noon, when Jupiter is wholly lost in the glare of the sky.

The only difficulty in seeing Venus in the daytime is to find her. She is bright enough, but very small —a mere luminous point to the naked eye, and to search for her in the sky is as difficult to seek as the proverbial needle in a haystack. If one knows approximately in what direction to look for the planet, a little patient sweeping of the sky with the eyes will usually be rewarded, but she is such a small object, and the region of sharp vision is so small, that one may sweep by the planet above or below several times before picking her up. Venus is a most unsatisfactory telescopic object; her great brightness and the beauty of her phases (which exactly resemble those of the Moon and change in the same way) are very impressive to the novice, but one may look at her many times and see no more. She appears as a uniformly white sphere with illumination shading off conspicuously but gradually towards the phase limb, and not a trace of definite markings. Under favourable conditions, faint, ill-defined, fugitive shadings may be seen on the bright surface, but nothing at all comparable with the conspicuous markings shown by Mars or Jupiter, or by the Moon to the naked eye.

It has been proved by two lines of evidence that the planet's rotation is slow. First, when she is nearest us, and also when she passes between us and the Sun, her diameter can be measured accurately.

On such occasions it has been found that her shape is practically spherical. We know that the earth's rotation causes her to bulge at the equator, so that the polar diameter is twenty-six miles shorter than the equatorial. No flattening at the Poles of Venus, however, has been detected. Second, some twenty years ago, at the Lowell Observatory, Professors Lowell and Slipher attacked the problem with the aid of the spectroscope. If the spectrum of the planet is photographed in such a way that the light which forms one side of the strip of spectrum comes from one limb of the planet, and that on the opposite side from the other, and if the planet is in rotation so that one limb is approaching us and the other receding, the lines in the spectrum will be shifted to the violet on one side of the spectrum and to the red on the other, so that they run across it obliquely and not at right angles. From measures of this slant, the rate of motion of the planet's equator, and hence the period of rotation, may be determined.

This method was tested with very satisfactory results on Mars, Jupiter, and Saturn, giving correct values for their rotation periods. But when applied to Venus it gave negative results. The lines in the spectrum ran squarely across it, and the most careful measurements showed that if there was any tilt at all, and hence any rotation of Venus, the tilt must be extremely small and the rotation very slow. Dr. Lowell believed that, as in the case of Mercury, Venus keeps always the same side toward the Sun, rotating once in 225 days, the period of her orbital revolution.

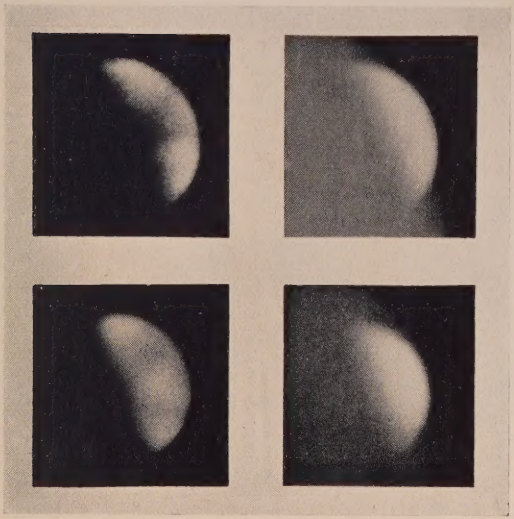
An alternative theory was proposed by Clayden, the English meteorologist. He describes in a very interesting manner the influence of rotation on the

distribution of clouds on the planet. He favours the belief that the planet's rotation, though slow, is more rapid than the orbital revolution, so that an observer on her surface would have regular alternations of day and night, but at relatively long intervals. Under these conditions the water would not be permanently frozen on one side of the planet, oceans might exist, and hence there might be abundance of evaporation to furnish clouds. Working out the atmospheric calculation, he infers that the hottest part of the planet would be an oval area where the Sun was nearly overhead, or a little past noon. In this region rising currents of air would bring up a considerable amount of moisture, and form dense clouds. Surrounding this in a sort of irregular ring would be a region of descending currents of air where the clouds would be thinner, and we might see portions of the surface through them. Beyond this, again, they should grow denser as far as the sunlight reached. On the dark side of the planet the sky might be partly clear. Far above these clouds, which might resemble our cumulus or "thunder-heads," would be thin, filmy cirrus clouds, which would contribute their share of the reflected light.

We have two pictures of conditions on our sister planet between which to choose, both of which are consistent with the known facts of science. One is of a dead world with one side a desert, hotter and more parched than any in Arabia, under the blinding glare of never-ending sunshine twice as warm as ours, while the other side is wrapped in perpetual night, and cold beyond the most piercing frosts of our polar winters. The other shows us a world which may be as much like our own in surface as it

unquestionably is in size and mass, with an atmosphere and oceans, rotating much more slowly than the earth, but yet so that the intervals of unbroken light or darkness are not as long as in our own Arctic or Antarctic regions, with a sky ever hidden with clouds thick enough to reflect away into space the dazzling beams of the Sun, leaving below them perhaps no more light, and no excess of heat above what we ourselves are familiar with—a world, in short, which might be well fitted to be the abode of life such as exists on our own earth.

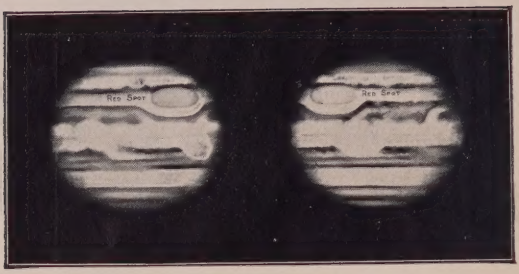
THE PLANET MARS, AS DRAWN BY
N. E. GREEN.



VENUS, NOVEMBER 23 AND DECEMBER 8, 1927.

(Lick Observatory, California.)

Facing p. 74



JUPITER, DRAWN BY SCRIVEN BOLTON.

SATURN.

(Mount Wilson Observatory, California.)

EXPANDING NEBULA ROUND NOVA PERSEI.

(Yerkes Observatory.)

Facing p. 75

CHAPTER XI

MARS

The planet Mars revolves round the Sun in an orbit that is pronouncedly elliptical. Though its mean distance from the Sun is 141 millions of miles, its greatest distance is 154 millions and its least only 128 millions. The earth's orbit is much more nearly circular, the greatest distance from the Sun being 94,500,000 miles and the least 91,500,000, and the two orbits are so disposed in space that the aphelion of the earth—its remotest point from the Sun—and the perihelion of Mars—its nearest point to the Sun—are nearly opposite to one another. If, therefore, the earth passes between the Sun and Mars at the time when Mars is in perihelion, the distance of the two planets is only 34,500,000 miles —the smallest possible value. Such a favourable opposition occurs always in the latter part of August, for it is at this time every year that the earth reaches the appropriate point in its orbit. Since it takes the earth a little more than two years to catch up with Mars, each successive opposition comes some 50 degrees farther east in longitude than the last, and the point of opposition works slowly round the Sun, taking about sixteen years to complete a circuit. Favourable oppositions, therefore, come at intervals of fifteen or seventeen years. The last one happened in 1924. At a favourable opposition its diameter is fully twenty-five seconds of arc and its brightness is nearly three times that of Sirius.

Under the best conditions two black markings

50 miles apart on the planet's surface could just be seen separately if each of them was about 40 miles in diameter. Looking at the Moon under similar conditions, we could see the largest of the craters upon her surface, but could get only an imperfect idea of the roughness of her topography, though the outlines of the light and dark areas upon her face could be made out in considerable detail.

Our belief that Mars has a much smoother surface than the Moon depends, therefore, not so much upon our failure to see the mountains by direct observation as upon the measures of brightness, which show that the planet falls off much less in light as the phase departs from the full than the Moon does, and hence that the number of shadows on the surface, too small to be seen individually with any telescope, must be much less on Mars than on the Moon.

For many years the study of Mars proceeded principally by means of visual observation of the details of its surface. These showed the seasonal changes of the white polar caps and the existence of permanent dark and green areas marking the planet's ruddy surface. The work of the last fifty years added the recognition of the faint, narrow, and elusive "canals," seasonal changes in the intensity and tint of some of the dark markings, and also led to the detection of occasional white spots, continuing only for a few days, which strongly suggested clouds.

The theory that the polar caps were snowfields, that the dark regions were areas of vegetation, and that the canals were narrow plant-covered watercourses, natural or artificial, gave a description quite in harmony with these phenomena; but, notwithstanding this, there was considerable doubt about it.

Within the last ten years, however, new and

powerful methods of observation have been applied. Drawings founded on direct visual observations and photographs on fine-grained plates have been made by Professor Slipher at the Lowell Observatory and by Professor Trumpler at the Lick Observatory. Both observers concur with one another and with the work of previous years in discovering a number of nearly linear dark markings or "canals" crossing the brighter and redder portions of the surface of the planet, in seeing ample detail within the large darker areas, and in the conclusion that the photographs give convincing evidence of the verity of the stronger canals and of the more prominent features.

A number of Dr. Slipher's photographs demonstrate how the dark regions grow larger and deeper in colour as the polar caps wane and the Martian spring advances; while on one of the photographs the dark markings on the opposite hemispheres, where autumn is changing to winter, are seen to fade.

Further information is procured by photographing the planet through screens of different colours, employing a reflecting telescope and special photographic plates. The images obtained with the violet light show the polar caps quite plainly, but only vestiges of the other markings. With deep red light the dark markings disclose great contrast, and the polar cap is scarcely brighter than some other regions. Photographs taken with intermediate colours reveal a gradation between these extremes. Dr. Wright, of the Lick Observatory, explains these differences as due to the presence of a moderately thick atmosphere around the planet.

Still more remarkable are the radiometric observations, which not only detect the heat which the planet emits, but make it possible to secure a fairly

good estimate of the surface temperature. These observations have been made at the Lowell and Mount Wilson Observatories. The results procured at the two Observatories are in perfect harmony. For the centre of the planet's disc—a region in the Martian tropics under a vertical sun—the temperature is discovered at Mount Wilson to be 7 degrees Centigrade, or 45 degrees Fahrenheit, while the values obtained at Flagstaff range from 7 degrees to 18 degrees Centigrade, or 45 degrees to 65 degrees Fahrenheit. Near the planet's limb, where the Sun is rising or setting, the temperature is found to be minus 13 degrees Centigrade or 9 degrees Fahrenheit from observations made at Mount Wilson, while the region of the polar cap gives about minus 70 degrees Centigrade, or 90 degrees below zero Fahrenheit.

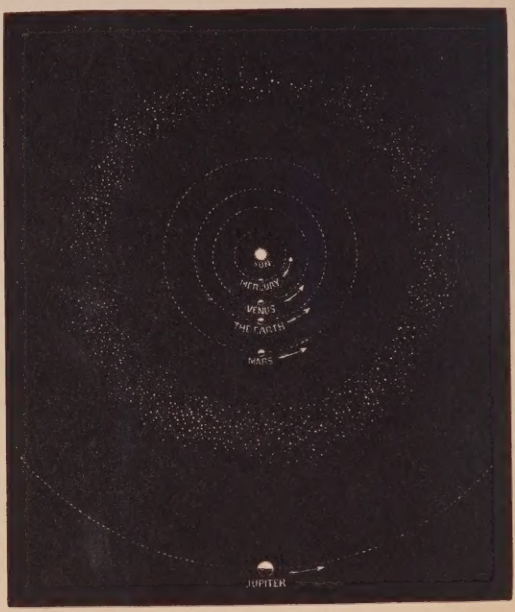
Finally, interesting studies by means of the spectroscope have given clear evidence that both oxygen and water-vapour are present in the atmosphere of Mars, although in much smaller quantities than on the earth. These important investigations speak, on the whole, very strongly in favour of the theory of Martian conditions which was developed by visual observers. The determinations of temperature make it practically certain that the polar caps are really composed of frozen water, and not of some other substance. The spectroscopic observations confirm this, and the presence of oxygen makes it appear that vegetation perhaps exists. If vegetable life exists on the planet, animal life may also exist.

CHAPTER XII

THE ASTEROIDS

Asteroids is the name given by Sir William Herschel in 1802 to what should more properly be termed, as they are sometimes, planetoids. These planetoids, now usually known as minor planets, are, as this latter name indicates, a numerous group of very small planets not visible to the naked eye, situated in the Solar System between Mars and Jupiter. The discovery of Uranus by Herschel in 1781, which first broke through the old opinion that the number of planets was complete, and the gap between Mars and Jupiter which Bode's law indicated should be filled by some planet, gave an impetus to the search for a new planet, which resulted in the discovery by Father Piazzi at Palermo, on January 1, 1801, of the first and largest of the asteroids, Ceres. Piazzi was making a catalogue of stars, and found that one of the objects he had observed was moving in the heavens, and was really a faint planet. It has a diameter of 500 miles, or one-fifteenth that of the earth, its volume being one three-thousandth of the earth's volume. On March 28, of the same year, Olbers at Bremen discovered Pallas. It is the smallest of the earlier discovered asteroids, and has a diameter of about 100 miles. Its period of revolution has been fixed at about 4·61 years. On September 1, 1804, Harding of Göttingen found Juno. This is the second largest of the asteroids, its actual diameter being about 400 miles. On March 29, 1807, Olbers found the fourth asteroid, Vesta. It has

the greatest albedo (that is, reflective power of the surface) and a diameter of about 250 miles. Revolution is performed in 3·63 years at a mean distance of 219 million miles from the Sun. Concerning the actual characteristics of these four little



Minor Planets.

planets not much is known. They do not appear large enough, even in the most powerful telescopes, to permit the detection of markings on their surface. These small bodies, doubtless, have no more atmosphere than the Moon, and, like her, must be dead worlds with no possibility of life or of any change on

their surface beyond the occasional splitting of a rock under the influence of heat or cold.

The most interesting and important of all asteroids is Eros. Until recently it was supposed that no other asteroid ever comes as close to the earth as this tiny body, which is numbered 433 in the constantly lengthening list of asteroids, of which there are over 1,150 well identified at the present time. There are, however, two asteroids now known which come nearer the earth than Eros. The discovery of Eros dates back to 1898, when, on August 13, G. Witt, at Berlin, noticed on a celestial photograph the trail of a moving object, the brightness of which corresponded to that of a star of the 11th magnitude. The unusual character of this asteroid was shown by its rapid motion across the star field, due to its proximity to the earth. Soon the orbit was computed, with the result that Eros proved to have a period of only twenty-one months, which means that its average distance from the Sun is less than that of Mars. But the most remarkable point was the fact that, on account of the high eccentricity (0·22) of the orbit, this planetoid can come very close to the earth. The inclination of the plane of the orbit was found to be 11 degrees to that of the earth, and this, combined with the appreciable eccentricity, produces considerable differences in the distance from one opposition to the next.

Numerous observations were gathered early after the discovery, so that good determinations of the orbit soon became possible. This showed that the object had been well in reach of photographic instruments in the past, and led to its identification on many plates taken as far back as 1893 at the Harvard College Observatory, and at the southern station at

Arequipa, Peru. These additional data confirmed the results of the preliminary computation, and made it possible to establish a much improved orbit. The future course of Eros could now be accurately predicted, and the interest in this object was greatly enhanced when it was noticed that the 1900-1901 opposition would happen near the time of perihelion, thus bringing the planet within one-third of the distance of the Sun, which is considerably less than any other asteroid had ever been known to do. This would afford an unexpected way of measuring with greater precision the dimensions of the Solar System expressed by the fundamental constant of the solar parallax. So far this constant had been determined, first, by measuring the parallax at the rare occasion of a transit of Venus across the Sun's disc, later and more successfully by determining the parallax of Mars, or, better still, of some of the nearer asteroids which can be measured with the same precision as stellar images.

Eros offered the best opportunity for applying this method, since the parallactic shift at the time of the minimum distance from the earth in 1900 would amount to three times that of the Sun. Elaborate preparations were made; international conferences gathered to discuss the best ways of carrying out the programme.

The solar parallax of 8·807 seconds determined by Hinks from a laborious discussion of the 1900-1901 material has, ever since, been considered as the best value available. Since then Eros has been kept under observation at each of its seventeen oppositions since the discovery, and no other asteroid has had its orbit determined with greater accuracy.

Incidentally, this work has furnished the best

available determination of the combined mass of the earth and the Moon, which has been deduced from the appreciable perturbation in the motion of Eros resulting from the earth's attraction.

Renewed interest has lately been awakened in Eros, due to the fact that in the month of January, 1931, the planet was at its nearest approach to the earth. The opposition came on February 17, one month after perihelion. The minimum distance from the earth was reached on January 30, the separation being reduced to 16,255,000 miles, about one-sixth of the distance of the Sun. From reasonable assumptions about the albedo, or reflective power of its surface, the diameter of this asteroid is only 15 miles. Its light is variable, and this is believed to be due to the effect of rotation of an irregular shape.

Up to 1891 the work of finding a new planet was a laborious one, although there were many to be found. The observer had to make a chart of some likely region of the sky along the ecliptic, near which all the larger planets lie; and then he had to go over this region again and again, looking for any faint star-like speck which was not upon his chart, and which might then turn out to be an asteroid which had moved into the field during the year.

But nowadays the work is done by photography. If a suitable lens be employed, giving good star images over a wide field of the sky, the chart is made automatically for observers in about two hours' exposure, and much more accurately and completely than could be done by the old method. Comparison of two plates taken at different times will reveal any planet which has come into the field of the observer, and this comparison can be made mechanically by the help of an instrument called the blink micro-

scope. The observer puts the two plates into his apparatus, and so adjusts them that the same region, as pictured on the one or the other, can be seen alternately by shifting a little mirror, without moving the eye from the eyepiece. If this alternation of images is made quickly and the plates are placed in their carriers so that the star images in the two appear in the same position in the field of view, then the stars will appear fixed, while any object which has moved or changed in brightness between the two dates of exposure will seem to flicker or blink.

The asteroid-hunter, however, does not require to provide himself with this expensive instrument. He can make the asteroid identify itself. All that is necessary is to prolong the exposure for several hours, guiding the time with an auxiliary telescope to make certain that the camera remains constantly pointed precisely right. The star images are then round black spots upon the negative, while the moving asteroids appear as streaks, or trails.

CHAPTER XIII

THE OUTER PLANETS

There is probably no heavenly body, except the Moon, whose telescopic appearance is better known, from descriptions, photographs, and drawings, to the general public than the planet Jupiter, and it is one of the favourite objects for amateur star-gazing.

This giant planet, at its mean distance of 483 million miles from the Sun, shows a wealth of surface detail. A small telescope brings out several bands or belts running parallel to the equator, while a larger one shows many finer markings, which can be seen to move across the disc as the planet rotates. The belts vary in colour from red to grey, and are sometimes bluish. These markings are not only changeable; they are in rapid motion. Those on the great bright equatorial belt show a rotation period of nine hours fifty and one-half minutes, while markings in higher latitudes take about five minutes longer for each revolution.

There is evidently a huge current flowing eastward around the equator and carrying the markings in the zone with it, which gains a whole revolution in about fifty days. Now, it is 275,000 miles around Jupiter, hence the current must flow with a velocity of about 250 miles an hour. The other bands are moving past one another at a slower rate. It appears from these facts that the markings on Jupiter are of atmospheric origin, and may well be called cloud belts and not features of a solid surface.

Of the nine satellites which attend Jupiter, a

3-inch refractor shows the four large ones. By making sketches of their apparent position with reference to the planet, the observer may easily satisfy himself, as Galileo did, that they are apparently oscillating backward and forward from side to side of the planet, which, of course, means that they are really going round it in nearly circular orbits, seen almost edgewise.

Comparative Sizes of Jupiter and the Earth.

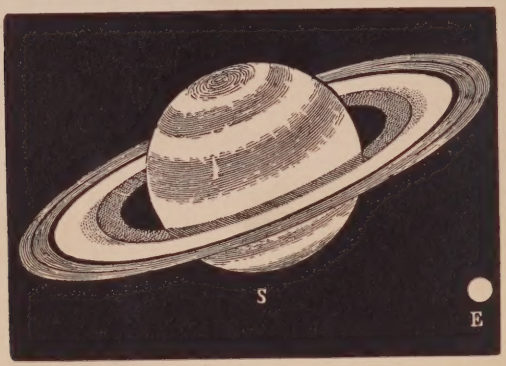
The outermost satellite takes sixteen and three-quarter days to complete a revolution. The next inside, which is the brightest of the four, seven days four hours; and the inner ones, three days thirteen hours, and one day eighteen and one-half hours. At the end of a week all three of these return very nearly to their original positions. The first satellite (counting outward from the planet, as is usually done) will

have made four complete circuits of its orbit in the interval, the second two, and the third one.

I may mention, in passing, that the satellites which, at a given moment, seem the farthest from the planet may not really be the most remote. The fourth and outermost of them may, at the moment we look at the system, be so nearly in line with the planet as to appear nearer to it than the first, though really far in front of it or behind it. Three of the satellites pass in front of the planet at every revolution, and also behind it, so that they are eclipsed in its shadow. These phenomena are of very frequent occurrence, but none the less interesting, especially the transits, when the satellite and shadow may both be seen on the planet's disc. The former appears as a bright speck when near the planet's edge, but usually dark when projected upon the planet's centre, which is much brighter than the limb. The shadows are, of course, always black. The fifth satellite revolves in a period of nearly twelve hours at a mean distance of 70,000 miles from the surface of the planet. The sixth and seventh satellites move round the planet directly in the same way as that of the motion of the large satellites. Their periods are 250 and 260 days, and their mean distances from the planet 7,114,000 and 7,292,000 miles respectively. The eighth satellite is of the 17th magnitude, and revolves round the planet in a period of 739 days, while the ninth has a mean period of 745 days, and is of magnitude 18·3. The mean distances of these two satellites are 14,600,000 and 15,000,000 miles respectively.

Saturn shows features similar to those of Jupiter, but its surface is much more quiescent. The belts are less sharply defined and less numerous, and

individual markings on them are rare. Sir William Herschel was the first to determine the rotation of Saturn, his value being 10 hours 16 minutes. Hale, in 1876, found 10 hours 14 minutes 24 seconds. A. S. Williams observed both white equatorial spots and dark spots in the North Hemisphere in 1893-4, and agreed nearly with Herschel and Hale. In 1903 remarkable spots appeared in the North Temperate region, and various observers showed a period of 10 hours 38 minutes. The eastward



Comparative Sizes of Saturn and the Earth.

current at Saturn's equator must, therefore, flow even faster than the one on Jupiter.

The mean density of both planets is low—namely, 1·34 times that of water in the case of Jupiter, and only 0·71 for Saturn. Moreover, from the relation between the polar flattening and the rate of rotation, it appears that in both planets the density is much greater near the centre than at the surface. The outer parts must be of very low density and probably gaseous, perhaps for thousands of miles below their

visible surfaces. The inner portions of the planets may be at a high temperature. The surfaces, however, are very cold. The radiometric observations of Coblentz and Lampland at Flagstaff, Arizona, show conclusively that we receive practically no heat from the planet except that carried by the reflected sunlight, and from this it may be computed that the surface temperature of Jupiter is about minus 140 degrees Centigrade, or 220 degrees below zero on the Fahrenheit scale, and that of Saturn still lower. From this we conclude that the upper atmospheres of these planets are composed of the "permanent gases," oxygen, argon, helium, while the clouds cannot be composed of water, or even of ice crystals, but must be formed of some substance like carbon dioxide, which condenses at a much lower temperature.

As to the rings of Saturn, each ring is not a continuous solid body, but is composed of separate particles of matter scattered in extensive swarms.

The satellites of Saturn are fainter than those of Jupiter, but the brightest of them, Titan, is visible with a small telescope of 3 inches aperture, appearing like a small star, revolving round the planet in a period of 16 days, at a maximum distance of about four and one-half times the greatest extent of the rings. Only Titan, the largest of the ten, shows a measurable disc, its diameter being about 2,600 miles and its mass nearly twice that of our Moon. The planet about which it revolves is more than 400 times as massive as Titan, and the Sun 3,500 times greater in this respect than Saturn itself.

Uranus

Uranus is the third of the giant planets in distance, but only fourth in the order of mass and size. The planet is so faint, on account of its great distance from the Sun, that it is barely visible to the naked eye even on the clearest and darkest nights. It appears like a star of the 6th magnitude, and can be observed with a field glass. To see the disc of the planet, which is only three and one-half seconds of arc in diameter, requires a telescope of 4 inches in aperture. The satellites—four in number—are visible only with the largest telescopes, and travel backwards—that is, they circle in a direction opposed to that in which all the planets of the Solar System, and all the moons of Jupiter and Saturn, as well as our own Moon, are observed to travel.

With a small telescope, Uranus seems a very insignificant object, which probably explains the remarkable fact that, though actually visible to the naked eye, it escaped detection for more than 150 years after the invention of the telescope. But in reality the planet is a very large body, far exceeding the earth in all respects. The mean diameter of the planet is about 32,500 miles, a little more than four times that of the earth, and less than half that of Saturn. Though exceeding the earth nearly seventy-fold in bulk, Uranus weighs only fourteen and one-half times as much as the earth—that is, the total quantity of material in the larger planet, though greater than that contained in the earth, is by no means proportional to its bulk. The density of the planet works out about one-quarter of that of the earth, or about 40 per cent. greater than that of water.

Uranus, like Jupiter and the other major planets,

has already cooled down on the surface, and shines only by reflected sunlight. The sunlight at this great distance from the Sun (1,800 million miles) is little more than one four-hundredth as bright as at the earth's distance. In consequence, the disc of Uranus looks very much fainter than a portion of that of one of the nearer planets of the same apparent size. Under favourable conditions faint belts have been observed on the disc. A number of years ago Professor Slipher at the Lowell Observatory obtained evidence regarding its rotation period. Spectroscopic observations showed a rotation period of ten and three-quarter hours, the direction of motion being retrograde. It is owing to this rapid rotation that the Poles of Uranus are more flattened than the earth.

Neptune

The discovery of Neptune is one of the most triumphant records in mathematical astronomy. Adams of Cambridge in 1845, and Leverrier of Paris in 1846, both determined its position from no other data than certain perturbations of Uranus. Galle, instructed by Leverrier, found the planet, September 23, 1846, within half an hour. Its magnitude is 8·5, and it is, of course, quite invisible to the naked eye. Its actual diameter is 35,000 miles, and its mass, as determined by the motion of its satellite, is 17 times that of the earth. The distance does not follow Bode's law,[1] being 2,800 million miles from the Sun. Its revolution period is 164 years, its velocity being about three and one-third miles per second. The spectrum is difficult to determine, and indicates the presence of a dense

[1] See p. 180.

atmosphere similar to Uranus, with a dark band in the red.

No definite markings have been seen upon its surface, and nothing is known of its rotation period; but it is supposed to be about fifteen or sixteen hours.

Neptune has one satellite, discovered by Lassell within a few weeks of the discovery of the planet. It is too small to show a disc, but, judging from its brightness, it is probably a little larger than our own Moon, and its distance from its primary—223,000 miles—does not differ much from that of the Moon from the earth. Its orbit is inclined 34 degrees 53 minutes to the ecliptic, but the satellite moves backwards—that is, in a contrary direction to the motion of its primary round the Sun—as is the case with the satellites of Uranus.

PLUTO, MARCH 2, 1930, 4 H. 56 M.

The arrows point to the planet and the large star on the left is Delta Geminorum.

(*Lowell Observatory, Arizona.*)

Facing p. 92

PLUTO, MARCH 5, 1930, 3 H. 44 M.

It will be seen that in the interval between this photograph and the preceding one, the planet has changed position relative to the surrounding stars.

(Lowell Observatory, Arizona.)

Facing p. 93

CHAPTER XIV

PLANET PLUTO

THE identification in the remoteness of space of the new planet, Pluto, confirmed on March 12, 1930, at the Lowell Observatory, Flagstaff, Arizona, is the most remarkable discovery in the astronomy of a century, the mathematical theory of Einstein perhaps excepted. It is so small a speck in the sky as to be visible only in the highest powered telescopes. It is far beyond the range of unaided human vision. To state its distance from the Sun is to give figures so vast as to be meaningless. According to computation, it is 3,586 million miles away—the earth is only 93 million miles from the Sun—and its year, or time of circling round its orbit, is equal to 249 of our years. By this finding of a planet moving far outside the path of Neptune, until recently the most remote of the known planetary bodies, the boundaries of the Solar System have been very greatly extended. Yet its existence has not come as a surprise to astronomers, who had long suspected that observed irregularities in the pace of Neptune were due to a remoter planet.

Since its discovery in 1846, Neptune has been only half-way round its orbit, and it is, therefore, practically valueless for locating an outer planet by means of its perturbations. Uranus has completed two revolutions since its discovery, and is quite available, but it is nearer the Sun and farther from the new planet, and the perturbations to be anticipated are, therefore, small.

Several investigators examined the question, the most comprehensive work being that of the late Professor Lowell, which was published in 1914, but commenced ten years earlier. A careful mathematical investigation indicated the existence of small perturbations just within the limit of detection, and indicated that the unknown planet which produced them must be either in the direction of the constellation Gemini or on the opposite side of the Sun.

Lowell estimated the planet's distance from the Sun as 43 to 44·5 astronomical units and its mass as one-third of that of Uranus. He estimated its probable brightness as from the 12th to the 13th magnitude. It is hopeless to search for such an object visually among the millions of the stars, and the only chance of success is by photography, employing substantially the same methods as have been used in finding asteroids—that is, the careful comparison of suitably duplicated plates of the same star fields.

After a time it became evident that the remote planet was fainter than the original estimate, and that a very powerful telescope would be required to find it. Within a year of the installation of the new telescope at Flagstaff, the long-sought planet was discovered. Photographs of moderate exposure, covering the whole region of the heavens around the predicted position, were obtained, and on one of them, taken on January 21, 1930, one of the Observatory staff found a very promising object close to the 3rd magnitude binary star Wasat in Gemini. It was identified from its motion past the many stars as revealed on plates of the same star field while being compared under the blink comparator. This showed that one faint star among many thousands

had shifted its place by a certain expected order of distance in the interval between the taking of the two plates. Since that date it has been followed both photographically with the 40-inch reflector and visually by Professor Slipher and other members of the staff. Its motion in the heavens has been just what might be expected of a planet beyond Neptune at the distance anticipated by Lowell, and its longitude agrees closely with his predictions.

The planet appears as a faint stellar point, and shows no sensible disc. The assigned magnitude—about 15—is photographic. Its movement among the stars is best studied photographically. Due to the fact that its revolution period is 249 years, its average annual eastward motion is very small, being only 1 degree 26 minutes 38 seconds. According to Dr. Crommelin, Pluto will not reach perihelion until December 5, 1984.

Little is known regarding its physical characteristics. Almost all that can be said is, that it is comparable with the earth in size, has relatively small mass, high density, and low reflecting power. It is practically in darkness, and the temperature on it is probably 380 degrees Fahrenheit below the freezing-point of water. It is, therefore, absolutely impossible for life of any description to exist there.

Coincidences

Photographic plates elucidated the mystery of a noteworthy parallel between the identification of Neptune and the new planet. In 1846 the astronomers Adams of Cambridge and Leverrier of Paris, by intricate calculations from irregularities in the motion of Uranus, concluded that there was a

new planet, and gave its approximate position in the heavens where Neptune should be, and where, in fact, it was found by Galle in Berlin near the predicted place. In 1822 the planets Uranus and Neptune were in line as viewed from the Sun. In and near this part of its orbit the disturbances produced by Neptune and Uranus would be greatest, and it was twenty-four years later, when Uranus had got considerably ahead of Neptune, that the latter was discovered. It is a further matter of interest to note that the interval from the discovery of Neptune to that of Pluto (1846 to 1930) is eighty-four years. Therefore, Uranus has been in the same place of its orbit on the occasion of the discovery of each of its more distant brethren. It is also worthy of note that the planet Uranus was discovered accidentally by Sir William Herschel on March 13, 1781, during an examination of a small group of stars in Gemini.

In our survey of the various members of our Solar System we have now seen that there are at least seven conditions necessary for the existence of life. They are conditions that must be met to make sure of the continued existence of water in a liquid form. If a planet comes short of one of these conditions, it probably fails as a possible habitation for life. Even if it meets all these necessities, there are other factors which may prevent high development of the terrestrial kind or even hinder the lowest origins. Life, as we know it, cannot possibly come into existence if the chemical constitutions of soil and air vary largely from terrestrial conditions.

The seven absolute necessities for organic origin and development on a planet of the Solar System are as follows:

First, the Sun or central star of the System must

be of essential constant brightness for our enormous period of time. Solar radiation is as fundamental for sustaining the energy of organisms as water is essential for protoplasmic chemistry. Light is the means of life, and light for the planets is entirely the effect of the activities of atoms in the solar atmosphere. The light which the planets receive from the stars is of no assistance, and moonlight is too feeble; besides, it is only reflected sunlight. If life is to continue, it is absolutely necessary that the Sun, on the average, radiate at a uniform rate. There is evidence that for the last several hundred million years its radiations have remained much the same as they are now.

Second, the distance of the planet must fall within certain limits from its primary, the Sun—a distance depending on the brightness of the Sun, so as to maintain water in a liquid form on the surface.

The third of the conditions necessary for life on a planet is the shape of the planetary orbit. The orbit must not be too elliptical, otherwise the temperature variations on the planet would be too great for the maintenance of life. Were the orbit very much elongated, like the path of a comet, there would be unusual variations in the amount of heat received from the Sun.

The fourth condition requisite for planetary habitability is that of mass—that is, the amount of matter in the planet. The mass of the planet must fall between two limits. If it be too small, an atmosphere cannot be retained. For instance, the Moon, with a mass one-eightieth of that of the earth, fails entirely as a habitable world. If the mass be too large, the obstacle to life as we know it would be the great amount of gravitation on its surface.

Fifth, the planet must rotate in a different period from its revolution—that is, its days and nights must not be so long as to prevent the existence of water in a liquid form.

Sixth, the inclination of the axis of rotation with respect to the plane of the orbit must be fairly high, so that the seasonal changes will be tolerable.

Seventh, a definite chemical constitution for air, land, and water is absolutely essential for the development of life such as that on the earth. So far as we can see, Venus more nearly fulfils the conditions than any planet other than the earth. Her mass, orbit, distance from the Sun, rotation, and chemical constitution seem to be favourable. The only difficulty in the way is that we cannot penetrate the thick covering of clouds and find out the secrets of her surface. As regards Mars, low forms of life may exist there. All the other planets of the Solar System are absolutely unsuited to protoplasmic life, owing to the seven conditions just mentioned.

Are there other Solar Systems than ours? Are there planets revolving around other stars as our planets revolve around our Sun? Is there life on planets in other Systems? We are powerless to answer these questions at present. Were we to transport our astronomers and their most powerful instruments to Proxima Centauri, our Solar System's nearest neighbour, they could not look back and see the planets which attend our Sun. They would see our Sun by the unaided eye as a 1st magnitude star; but our giant planet Jupiter would be a star of the 21st magnitude, and their telescopes at Proxima Centauri would have to be at least 25 feet in diameter in order to show Jupiter as a stellar point of light just on the limit of vision, even though the flood of

light from our Sun did not interfere with the observation.

Although we have not been able to secure direct and positive evidence in favour of other planetary systems, and although we see no promise of such evidence in the future, it would be unreasonable to believe that such planetary systems do not exist. It would be contrary to the simple probabilities if our Sun, one of thousands of millions, were the only one attended by planets, and our earth were the only planet that is the abode of life. If planetary systems other than our own actually exist, the same conditions hold for them as for our Sun and planets.

We must also bear in mind that many of the stars are binaries, many are variable in light, many are located in nebulous regions, many are involved in dense clusters—around none of these could the constant and genial conditions necessary for life be long maintained.

Nevertheless, among the thousands of millions of stars, there may be numerous other living earths that conform with the requirements of life, and it is quite possible their life phenomena may pass in intricacy and highness those on the earth.

CHAPTER XV

COMETS

Modern science has not taught us much as yet concerning the physical nature of comets. Without the use of technical language, we will endeavour, however, to outline some of the more important results of observation and reflection upon this subject.

Comets are seen in their simplest form as faint patches of nebulous light. They are usually circular or oval in outline, without remarkable difference of brightness from centre to circumference. At a later stage of development the comet shows a diffuse brightness in its central parts, known as central condensation. When a large comet approaches the Sun, the structure becomes far more complex. The centre condensation gathers intensity. Finally, a point or disc of light appears near its centre, which shines with a light approximating that of the planets. This is called the nucleus. Observers with powerful telescopes usually find that what we commonly call the nucleus has no definite magnitude. It continually measures less with increase of optical power. The inference is, that the real nucleus must be very small, and much obscured by the vapours which surround it. Generally the nucleus appears to shrink in size as it approaches the Sun. The most plausible explanation seems to be that with lessened distance from the Sun the real nucleus gets hotter and brighter, and the vapours near it become more transparent. The spectroscope seems to show that it is

a solid or liquid incandescent mass. The matter surrounding it contains hydrogen and carbon in one of their numerous compounds.

A second feature in comets is called the coma, or head. It is usually found that it appears much brighter on the sunward side. In many cases streams of matter appear to issue from the nucleus on that side. These assume a variety of forms, and are almost always curved backward from the direction of the Sun at their extremities. Above the streams or jets are sometimes seen one or more arcs of light, concentric with the nucleus from which they appear to recede. These envelopes, as they are called, are supposed to be hollow segments of matter more dense than the surrounding parts of the coma. One important characteristic of the matter which surrounds the nucleus is well established. The rays of light from distant stars seen through it are not sensibly bent or refracted. This shows that gases of an appreciable amount do not exist in comets.

A third feature in comets is their tail. The strange appearance of the tail, and the gigantic dimensions it sometimes attains, are well calculated to arrest the attention of mankind. It is not wonderful that the ancients should have regarded the tails of comets with trembling apprehension, nor is it surprising that, even yet, they excite an absorbing curiosity among the educated and the superstitious terrors of the ignorant. The matter of which they are composed must be expanded to an almost inconceivable degree, for even when they are millions of miles in thickness the light of faint stars is seen through them with scarcely diminished brightness.

When a comet is seen at an immense distance from

the Sun, the only parts visible are the coma and the nucleus, but as it approaches the Sun the tail stretches out to a vast extent. The comet of 1744 had a six-fold tail, which formed a glorious fan. Its length was 19 million miles. This rare phenomenon is supposed to be connected with certain rapid changes which the gaseous substance of the comet undergoes on approaching the Sun. The great comet of 1577, seen with the naked eye before sunset, was divided into two streams. The length of the tail of Newton's comet, 1680, was 100 million miles, while that of 1769 was 40 million miles. The tail of the comet of 1882 was 100 million miles in length, while that of 1843 was twice that length. In receding from the Sun the tail of a comet becomes less, and vanishes before the coma and nucleus disappear from view. It is interesting to note that a comet's tail always points away from the Sun. It does so owing, probably, to the light pressure caused by the Sun, which operates upon the gaseous matter and particles discharged from the coma.

This material shines by its own light, and reveals itself spectroscopically as a mixture of familiar gases, carbon compounds, cyanogen, carbon monoxide, and nitrogen. The remainder reflects ordinary sunlight and is probably some kind of very fine dust. The pressure of the Sun's light upon the minute particles of dust and molecules of gas expels the gases and dust away from the Sun.

A circumstance worthy of note is the apparent gradual disintegration of comets. Comets seem subject to steady depletion of their own substances by the very processes which make them conspicuous. The greater appearance a comet makes, the more quickly it is probably wasting away, for the gas and

dust which are expelled from the nucleus to form the coma and are carried away by radiation pressure to make the tail never return. By study of photographs it has been found that the tail particles move faster the farther they go. The tail fades out at the end, not because the gases have completely ceased to shine, but because they are spread out so widely that the light no longer affects the eye or the photographic plate. Were it possible continuously to watch a comet long enough, one would probably notice it wearing itself out gradually, and the tail growing smaller and smaller at each return.

But it is not necessary to wait to notice things happen to individual comets. There are a number of short-period comets which return to perihelion every five, six, seven, or eight years. Not one of them is conspicuous, and many of them appear to have lost most of their tail-forming material. Biela's comet, for instance, which was an easy telescopic comet 100 years ago, has practically faded out and is now lost. Among comets of the same age we should expect those with short periods to wear out much faster than those which have long periods.

A test of this has recently been made by Bobrovnikoff, a Russian astronomer. He has gathered, from different sources, determinations of the brightnesses of 94 comets of known period, ranging from three years to several millions. Plotting these against the periods, he finds that comets with long periods average the brightest, and those of shortest periods the faintest. This accords well with the results of the theory of gradual disintegration. It seems, therefore, possible that millions of years ago the comets of our system were more numerous and brighter.

We shall now turn our attention, briefly, to the

origin of comets, their number and their history. Astronomers, after careful consideration and diligent investigation, have found that comets are *bona-fide* members of our Solar System, and travel in paths of elongated ellipses. The great majority spend most of their time in the outer parts of our System far beyond the orbits of Neptune and Pluto, but they are moving through space as companions to our Sun as really as the earth is.

Before the invention of the telescope there were recorded 400 comets which were seen with the naked eye. Many of these were of an enormous size, and approached closely both Sun and earth. During the past 350 years there have been found 450, the majority of which have been discovered with the telescope. The half of this number has been found within the last fifty years.

In addition to the comets which travel in orbits of very elongated ellipses into regions far removed from the Sun and planets, there are the so-called periodic comets which move in relatively short ellipses, revolving round the Sun in a few years and reappearing at predicted times and places. Sixty-eight such comets have been observed with periods less than a hundred years. There is the great Jupiter family of comets—about fifty in the family. Their periods of revolution vary from three to nine years. Their motions round the Sun are all from west to east, as in the case of the planets.

In a similar way there are two Saturn comets. One of them was discovered by Tuttle in 1858, and bears his name. Its period of revolution is $13\frac{3}{4}$ years. The other was discovered by Peters in 1846. Although its return was computed to take place in $13\frac{1}{2}$ years, it was never seen again.

Uranus has also a family of three. The first is Coggia's comet. Its period of revolution is 306 years. The second is Tempel's comet of the November meteors; the third is Stephan's comet of 1867. A period of 40 years and 1 month was calculated, but it was not observed.

There are nine Neptune comets, one of which is Halley's. The names of six others are Pons' of 1812, recovered by Brooks in 1883; Olbers' of 1815, recovered by Brooks in 1887; Brorsen's of 1847, recovered by Metcalf in 1919; Westphal's of 1853, recovered by Delavan in 1913; De Vico's of 1846; lastly, Pons and Gambart's in 1827, which has a revolution period of about 64 years. The Neptune comets complete their circuits in periods ranging from 60 to 81 years.

As to the history of these periodic comets, a theory held among astronomers is that they have been captured by the major planets, and especially by Jupiter—that is, that comets approaching the Sun in their elongated orbits, and passing close to the major planets, have had their orbits converted, either during one visit or during several visits, into the forms we now observe.

There must be some cause for the large number of comets with periods of about 6 or 7 years. The correct explanation of this was realized 150 years ago. A fairly bright comet was observed in June, 1770, which, according to the calculations of Lexell, had a period of only 5 years and 7 months, and hence should have been seen at later returns, but was never found. Laplace, the great mathematical astronomer, showed, however, that in 1779 the comet had come very near Jupiter, and that its orbit had been entirely changed by the attraction of the planet, so that after-

wards it never came near enough to the Sun to be visible. Moreover, on calculating backwards, he found that in 1767 the comet had also been close to Jupiter, and had undergone a great change in its orbit, and that before that date it had also moved in a path so far from the Sun that it never grew bright enough to be visible. The comet had thus been captured by Jupiter in 1767 and made into a short-period comet, because the effect of the planet's attraction was to slow up its motion, which necessarily, by the theory of gravitation, involved making its orbit smaller; so much so that, in spite of the slower motion, it got around in less time than before. There is good reason to believe that all comets of short period have been similarly captured by Jupiter; that is, they were moving originally in much larger orbits, and, having at some time come very near the planet and had their motion slowed by its attraction, have been diverted into the paths in which they now move.

Some of the most remarkable comets of modern times are the following: Biela's comet was first seen on March 8, 1772, by Montaigne of Limoges, and was rediscovered by Pons on November 10, 1805. It was again seen by Biela, of Josephstadt, in Bohemia, on February 27, 1826. Clausen, Biela, and Gambart, all determined its orbit and its period of revolution, about $6\frac{1}{2}$ years. Its return in 1832 caused widespread alarm, because it was believed it would strike the earth. A very remarkable phenomenon attended the perihelion passage of this comet in the latter end of 1845. It became divided into two comets, which did not again reunite, but travelled along together in similar orbits. It was believed that a near approach to Jupiter in 1841 was the

cause of its disruption. Instead of its expected appearance in 1872, there was a large display of meteors on November 27. The display was repeated in 1885 and 1892. There has been no return of the comet since, and the meteors, called the Andromedes, have been fewer.

Probably the most magnificent of all was the great comet of 1811. Its nucleus or head had a diameter of 1,250,000 miles, and its bulk was nearly three times as great as that of our Sun and 400,000 times as large as the earth. Its tail stretched out to the enormous distance of 130 million miles. It remained in view eighteen months. The revolution period of this comet is 3,000 years. It travels to the tremendous distance from the Sun of 41,121 million miles.

Another notable comet was that of 1843. Its tail was enormous, reaching in length 200 million miles. This comet completes its journey round the Sun in a period of 376 years.

Donati's comet was discovered on June 2, 1858, by Donati at Florence. At first it appeared as a faint nebulous patch of light, but in September it became visible to the naked eye. A short tail was then on the side opposite to the Sun. The development was afterwards rapid, and in the first week of October the tail attained its greatest length of 36 degrees. Its nearest approach to the earth was about equal to half the distance from the Sun. It returns to us only once in 2,000 years.

Another large comet was that of Coggia, which appeared in July, 1874. It was remarkable for the series of envelopes of luminous matter which seemed to combine to form its tail.

Wells's comet, called the "Great Southern" of

1882, which passed within $5\frac{1}{2}$ million miles of the Sun, was visible in broad daylight for three days. Its progress was closely watched until it was lost in the Sun's rays, and entered the corona to the depth of 100,000 miles. Its outward journey was followed, with the aid of a telescope, for about 500 million miles from the Sun. It revolves round the Sun in a period of 772 years.

On January 19, 1910, an unexpected comet of the greatest brightness since 1882 made its appearance. It was discovered in the southern hemisphere. It was seen distinctly with the naked eye in broad sunshine, both in South Africa and in the southern countries of Europe, and was called the "Daylight Comet." Its perihelion distance was about 4 million miles.

One of the best-known comets is called Halley's. At its last return it first became visible in the autumn of 1909, and on April 19, 1910, it was at its nearest approach to the Sun. Its probable position had been most carefully computed by Drs. Cowell and Crommelin of Greenwich Observatory, who had taken every possible circumstance into consideration, including the influence of all the planets that would be likely to affect the progress of the comet as it approached the Sun, and an Ephemeris was compiled with the assistance of Dr. David Smart, on the assumption that the date of the comet's perihelion passage would be April 16, 1910, at a distance of about 54 million miles.

Records of this comet have been preserved from 87 B.C. From that time forward, with the exception of A.D. 912, the accounts of its periodical visits are plainly traced, its periods of revolution varying from a maximum of 79 years to a minimum of $74\frac{1}{2}$ years.

HALLEY'S COMET, MAY 13, 1910.
(Lowell Observatory, Arizona.)

DAYLIGHT COMET, JANUARY 27, 1910.
(Lowell Observatory, Arizona.)

Facing p. 108

GREAT BOLIDE, SEPTEMBER 12, 1923.

(Klepesta, Prague.)

EXPLODING ANDROMEDID METEOR, NOVEMBER 23, 1895.

Facing p. 109

An account of its appearance in A.D. 66 is given by Josephus, who describes it as hanging over the city of Jerusalem in the form of a sword for over a year, foretelling its destruction in A.D. 70. Another notable apparition took place in 531, in the reign of the Emperor Justinian. Its imposing appearance in 1066, a few months before the Norman Conquest, caused great consternation in this country and in France, but William of Normandy, on recovering from his alarm, declared it to be "a sign that a Kingdom wanted a King." This comet, and also that of 873, were identified as Halley's by Russell Hind, whose calculations were confirmed at Greenwich about 23 years ago.

At its return in 1456 it must have been very large and bright. Its tail is said to have measured 60 degrees in length. Much alarm was felt in Europe at this time owing to a dreaded invasion by the Turks, but there appears to have been little or no foundation for the old story that Pope Calixtus III. added the following prayer to the Ave Maria: "Lord! save us from the Devil, the Turk, and the Comet." At this return it was first seen on May 19, and it was nearest to the Sun on June 9.

Edmund Halley, born in 1656, was the friend of Isaac Newton and the successor of Flamsteed, the first Astronomer Royal. He was not the discoverer of the comet of 1682, but, on the announcement by Flamsteed's assistant of its arrival on August 15, Halley resolved to make it the object of his special study, and he was at last so convinced of its identity with the comets of 1607 and 1531 that in 1705 he ventured to predict its return in 76 years. He wrote: "I am very much inclined to think that the comet of 1531, observed by Apian, is identical with

those that reappeared in 1607, as described by Kepler, and in 1682, when I myself observed it. For the elements of all three are the same, and the only marked difference in them is the time occupied by their revolutions." Knowing that he would not live to see the prediction of his prophecy fulfilled, he wrote: "If it should return according to our predictions about the year 1758, impartial posterity will not refuse to acknowledge that this was first discovered by an Englishman." Sixteen years after the death of Halley in 1742, the comet, true to his prediction, returned. It was first seen on the Christmas evening of 1758 by a Saxon farmer living near Dresden, George Palitzch by name, an enthusiastic amateur astronomer who had in his possession a good telescope. Messier, the distinguished astronomer, had also been on the look-out for it for some time, and he was greatly disappointed on finding that he had lost the honour of its discovery. He was, however, the last to see it during its return journey on June 3, 1759.

Much interest had been excited in its predicted appearance, and the French astronomers Lalande and Clairaut believed that its progress would be considerably delayed by the attractions of Jupiter and Saturn. Their calculations turned out to be correct, for it was delayed a year longer than on its previous visit in 1682.

Considerable interest was again excited at the return of Halley's comet in 1835. Count de Pontécoulant, a French astronomer, had predicted that it would return to the point of its nearest approach to the Sun on November 12, four days earlier than its usual occurrence. It was first seen by Father Dumouchel in Rome on August 6, and it was

carefully watched throughout its course by several famous astronomers. The tail began to develop on October 2, and during a period of about five days a short tail of a fan-like shape was expelled towards the Sun, and was then thrown backwards by the repulsive force of the Sun. At that return the wasting process, as the result of the comet's swift dashes round the Sun, was quite apparent, for the tail was not so long by several degrees as it was on May 5, 1759, when it measured 47 degrees. After making its great curve round the Sun, the comet rapidly passed into the southern hemisphere, where Sir John Herschel, at the Observatory, Cape of Good Hope, carefully followed its course across the southern skies.

In the middle of May, 1910, streamers and envelopes were seen to issue from the nucleus, while fainter material was observed outside of this. After perihelion a new feature developed in the coma in the shape of a bright spherical halo.

With the exception of Halley's comet, all the brilliant comets have periods of such enormous length that they have not been seen for many years.

A few words in closing regarding the influence of comets upon the earth. Comets might, like the Sun, affect the earth's magnetic condition, and thus, to some extent, possibly its meteorology. No such effect has, however, been perceived. In spite of some chance coincidence between the apparitions of some great comets and remarkable public events, no well-informed person now believes that there is any real connection between them.

When a comet is converted into meteoric bodies which impinge upon the earth's atmosphere, there is some direct, though probably infinitesimal, effect. Some have thought that a sensible portion of the heat

which the earth receives might be generated in this way; but the weight of scientific opinion is against that hypothesis. The impact of meteors upon our atmosphere must add some matter to it, and this is probably in the form of dust. This may be the origin of the so-called cosmic dust which has been collected at sea on plates exposed for the purpose. A more remote effect may be sought in the possible fall of meteors and comets upon the face of the Sun. Owing to his vast mass and bulk, the Sun would attract an immense number of these bodies; but it is quite certain that their effect upon the Sun's heat is insignificant.

Finally, it may be said that the appearance of a great comet exerts one important influence on the earth, in that it stimulates the curiosity of mankind and directs their thoughts to the more particular contemplation of the glorious universe which surrounds them.

CHAPTER XVI

SHOOTING STARS AND METEORITES

One cannot watch the sky for an hour on a clear evening without seeing star-like specks of light which flash across the heavens and vanish in the twinkling of an eye, leaving a faint trail of light behind them, which endures for a moment or two longer.

Sometimes there are many, while at other times there are only a few. There are more in the morning hours before dawn than in the evening hours. These darting points are the shooting stars, so called if they are not brighter than the bright fixed stars. They are thousands of times nearer than even the Moon. They are little lumps of matter which have been pursuing their paths through space for ages, moving through the almost perfect vacuum of interplanetary space without disturbance. Fate at last carries them towards the earth, and no sooner do they enter the outer confines of our atmosphere than they meet with such friction that, in an instant, they flash into incandescent vapour and vanish. But occasionally some appear which far outshine Venus, and some burst into showers of sparks. These big bright ones are called fire-balls, meteors which light up the landscape like the Moon. Such fire-balls take several seconds in their flight and leave a long luminous train, which sometimes remains visible for two or three minutes. Occasionally a meteor is heavy enough and goes slow enough to pass through the atmosphere and strike the surface of the earth somewhere. Of course, most of these fall into the

sea, but others fall on the land, while a few are picked up or dug out of the holes they burrowed. They strike the earth with such tremendous force that they are sometimes buried to the depth of 10 or 12 feet. These picked up meteors are called meteorites, meaning meteoric stones.

When the speed of these meteors falls below 8 or 10 miles a second, the surface is no longer kept incandescent. The mass cools very rapidly, since the heating is so fast as to be only skin-deep, and the meteor reaches the solid earth with a slow speed like a spent cannon ball. It is often at a white heat on reaching the earth, and frequently, when of great size, requires several hours to cool.

I shall mention, briefly, a number of the most remarkable meteorites. We can trace more or less authentic records as far back as 3,000 years. The following are examples of ancient falls. Livy, Rome's greatest historian, mentions the falling of a shower of stones on the Alban Mount near Rome, 654 B.C.

Herodotus, the "father of history," supposed to have been born about 484 B.C., alludes to a fall of meteoric stones (lib. iv., cap. v. and vii.). The interpretation of this well-known passage is that the first of the Scythians, Targitas, had three sons, who happened one day to witness the fall of a splendid meteorite. The eldest son approached it, but it was so hot he could not touch it. The second followed, but it burnt his fingers likewise. At last, after some time, the youngest son, Colaxais, approached, and (the meteorite having by this time cooled) he carried it off. "The two elders, understanding what was meant by this prodigy, gave up the kingdom to the youngest."

One of the most remarkable instances of an

ancient meteorite is that described by Plutarch as having fallen in the year 465 B.C. at Ægos Potami in the Hellespont, near the modern Gallipoli. This stone is also mentioned by the elder Pliny (book ii.), who saw it about 500 years afterwards. It is said that it was of a huge size—in fact, as large as a waggon—and that its colour showed that it had been under the action of fire.

There are several recorded falls of meteoric stones scattered over the works of ancient writers, especially in the Chinese annals, which extend as far back as the year 720 B.C. A Chinese catalogue records the fall of a meteorite on January 14, 616 B.C., which broke several chariots and killed fourteen men.

Some sacred stones, as the black stone worshipped at Emesa in Syria, and at Mecca, and the great stone of the pyramid of Cholula in Mexico, owed their sanctity to a report, probably true, that they had fallen from heaven.

It has been suggested that the earliest image of Diana of the Ephesians, which "fell down from Jupiter," had taken the place of an actual meteorite.

I shall now allude to several remarkable falls which occurred in the Middle Ages, and in the seventeenth, eighteenth, and nineteenth centuries.

On November 7, 1492, a stone weighing 260 pounds was seen to fall near Ensisheim in Alsace. A portion of it is still preserved in the village church there.

In 1510 about 1,200 stones fell near Padua in Italy. The two largest weighed 120 pounds and 60 pounds respectively.

On November 27, 1627, the astronomer Gassendi witnessed the fall of a stone weighing 59 pounds at Mount Vasier in Provence.

Historical records show several instances of people being killed by these bodies. In 1650 a monk was killed near Milan by the fall of one, and according to Humboldt, in 1674, two Swedish sailors on board ship were likewise killed.

On December 13, 1795, at Wold Cottage, Yorkshire, a ploughman saw a stone of 56 pounds weight fall near him in a field.

In April, 1803, in Normandy, there was a shower of nearly three thousand stones, the largest of which weighed 17½ pounds.

In Northern Central Arizona, at Coon Bute, there is a nearly circular crater in the middle of a high hill. The crater is about 4,200 feet in diameter, and the surrounding rim, formed of ejected rock fragments, rises at its highest point 160 feet above the plain. It has an inside depth of about 500 feet. It is, therefore, nothing like the average volcano; and, on other grounds, it cannot in all probability be volcanic, as it lies in a non-volcanic neighbourhood. The rock in which the crater has been made is composed of horizontal sandstone and limestone strata. Between three and four hundred million tons of rock fragments have been detached, and a huge portion hurled, by some cause, out of the crater. The region has been known for many years, owing to the masses of meteoric iron found scattered about, and known as the "Canyon Diablo" meteorites. These meteoric irons are scattered about the district within a radius of two or three miles.

In 1903 shafts were sunk and holes were bored to a great depth in the interior of the crater, in the endeavour to find the original meteorite. In 1920 material of unmistakably meteoric origin was found by means of the drills, mixed with crushed rock, to

a depth of 1,300 feet below the floor of the crater. This gave convincing proof of the formation of this immense crater and the falling of the meteoric iron out of the heavens. The rock strata present every appearance of having been violently upturned by a huge body penetrating the earth like a cannon ball.

In the following rapid indication of other remarkable falls I shall restrict myself to some from the year 1865 to the present time.

In 1865 a meteorite was presented to the British Museum which weighs 3½ tons. It was found near Melbourne.

A large meteorite lies on the plain of Tucuman in South America. Its weight is about 15 tons and its length 8 feet. It was half buried in the ground when discovered.

In 1866 a meteorite weighing 660 pounds fell at Kuyahinya, Hungary, and penetrated the ground to a depth of 11 feet.

On April 20, 1876, a mass of meteoric iron, more than 7 pounds weight, fell at Rowton in Shropshire, accompanied by an explosion.

One of the largest meteorites is one known as the Anighito meteorite. It was brought to America by Peary, the explorer, who found it at Cape York in Greenland. Its weight was estimated at about 90 tons.

On July 24, 1896, a very large meteorite weighing 27½ tons was reported to have fallen in the neighbourhood of the mines of Santos Reges in the Chikuahna State, Mexico. The fall was accompanied by a loud report. After striking the side of a hill and rolling for some distance, the meteorite buried itself in the earth.

In August, 1897, the Foreign Office Annual

recorded the fall of a meteorite in Bosnia. The fall was accompanied with a noise like thunder, lasting several minutes, and audible a long way off. It left a fiery streak, above which was a thick cloud of smoke. It buried itself 3 feet in the ground, and pieces were knocked off by peasants.

In *Nature*, October 9, 1902, there was reported the fall, on September 13, 1902, of a meteoric stone near Crumlin, in the County of Antrim, weighing 9 pounds $5\frac{1}{2}$ ounces. It fell within 20 yards of a labourer, who at once procured a spade and dug it up from a depth of 18 inches, where it had been stopped by impact against a much larger terrestrial stone. The stone was hot, and remained warm to the touch for more than an hour. The sound was heard at places as far as 13 miles away. The meteorite was sent to the Natural History Museum, South Kensington.

On June 30, 1908, a huge meteorite fell in the forests of Northern Siberia, and some reports are on record. Natives outside the area of destruction gave terrifying accounts of their experiences. It devastated a large area some 30 to 40 miles in diameter, but no great crater was made, as it fell in marshy ground. Herds of reindeer perished in the fall, and the forests in the area were laid flat and seared, presumably by a blast of superheated air which splashed out as the meteor fell. The sound, as it struck, was heard hundreds of miles away. The meteor was perhaps a fragment of Pons-Winnecke comet, and it is, of course, fortunate that it fell in a practically uninhabited region of the earth. Had it fallen in Aberdeen, for instance, the whole of the city and its suburbs would certainly have been destroyed. The fall of the Siberian meteorite and the meteor crater, Arizona,

show that the impact of the head of a comet with the earth, if it happened in a populous region, would be a very serious matter.

A meteorite was reported by the late W. F. Denning, F.R.A.S., Bristol, in the *Journal* of the British Astronomical Association in February, 1918. On December 3, 1917, many persons in Edinburgh, Perth, and Forfar saw a brilliant meteor, which gave a startling flash and several thunder-like detonations. The sound heard indicated the disintegration of the meteor and its comparative proximity. Three fragments fell—namely, (one) at Keithick Lodge, 2 miles south-west of Cupar-Angus, weighing 2½ pounds, where it penetrated the slate roof of the house; (two) at Carsie Farm, about 2 miles north-west from Keithick, weighing 2¼ pounds, where it was seen to fall into a grass field by a farmer's wife standing about 20 yards away; and (three) near Easter Essendy, 2 miles south-west from Blairgowrie, weighing 22½ pounds, where it embedded itself in a grass field to the depth of 20 inches. Enquiry as to the nature of the objects proved them to be genuine meteorites.

Another fragment weighing 2¼ pounds fell at Corston. The four pieces seem to have been distributed over an area 6 miles in length from south-east to south-west. A great number of other examples might be cited, occurring in different parts of the world—Europe, India, the Cape, and America.

Meteorite of April 14, 1931

About noon on April 14, 1931, a meteorite fell to the earth at a farmhouse in Pontllyfni, Llanwnda, Carnarvonshire. The following account of the

actual descent of the meteorite appeared in the *Manchester Guardian*: The meteorite fell within 50 yards of the farmhouse. Weight, exactly 5 ounces. It made a hole 9 inches deep in hard ground. Mr. John Lloyd Jones (tenant of Coch-y-Bug) was not more than ten paces from the spot when it came down. He was startled, shortly before noon, by what he took to be a clap of thunder. He walked 200 yards towards the farm-buildings, when he heard a rushing, whistling sound. "I stood still," he added, "and shouted to my son, and then behind me I heard a dull thud. Not knowing what was going to happen, I ran a few steps towards one of the outbuildings. Then my son came up, and he took out of a hole in the ground what seemed to be a stone." His son said: "I heard a succession of reports like muffled guns, and about a minute later there was a peculiar whistling noise as of a projectile. Instinctively I stooped where I stood in the farm-yard. When I picked up the fragment of metal it was warm in my hand." On enquiries being made, it was found that two persons had seen a bright meteor at a little before noon on the date in question, and that the flights appeared to be roughly in conformity with the idea of a meteorite-fall in Carnarvonshire. One of the observers said: "The meteor left a fiery trail, and seemed to burn itself out and disappear well above the horizon." Mrs. Jones stated that "the hole made by the meteorite was nearly vertical." The meteorite certainly disappeared as a visible fire-ball shortly before it reached the earth. On being examined, it was pronounced to be a genuine meteorite.

We shall now pass on to speak of the chemical composition of meteorites and the origin of their fall.

Meteorites are (1) all metal, (2) iron-stone, (3) stony or aerolites. The latter contain less iron and nickel and more silicon and magnesium oxides than the first two. There are many examples of stony and iron meteorites in our museums. When you see them, you will notice that they are commonly covered with a crust, like a dark, thin layer of varnish, as if the outside had been melted so suddenly that the heat had not gone far in.

As to the origin of the fall of meteorites, there are wide differences of opinion, which resolve themselves into two main theories. Some assert that they are the same as shooting stars, that every shooting star must be a solid body, and that meteors are solid fragments of certain known or unknown comets coming into our atmosphere. Others, on the other hand, hold that meteorites have had a volcanic origin on some celestial body, probably the earth itself. They hold this opinion from the fact that meteorites are always angular fragments, as if torn from some parent mass before they reach the earth; that they often present similarities of structure to that of volcanic tufas. It is quite possible that meteorites were projected from the earth in the earlier stages of its history when its volcanic force was more intense. To leave the earth, a body would require an initial velocity of 7 miles per second. After accomplishing an elliptic orbit round the Sun it would pass through the track of the earth, and at every subsequent revolution it would pass through the same point. Thus, according to this theory, the earth, whenever she receives a meteorite, is gathering back to herself the fragments launched into space in an earlier period of her history.

It may be interesting now to give a brief descrip-

tion of shooting stars. They have a long history, for not only do they burst out here and there once in a while, but there have been nights when no earthly fireworks ever gave such a show anywhere. Among the earliest records of such a phenomenon is the statement by Theophanes that in November, 472, at Constantinople, the sky appeared to be alive with shooting stars. In the month of October, 902, again, so many shooting stars were seen that the year was afterwards called "the year of stars." The Arabs connected this fall with the death of Ibrahim Ben-Ahmed, which took place on the night of the star-shower. The year 1029 was also remarkable for a great star-fall. On April 4, 1095, a shower of stars occurred over this country and France. This was considered by many as a token of God's displeasure with King William II. It is not necessary to mention any more of these ancient meteoric showers, except to state that the dates have been satisfactorily proved, and that they have done good service as data for modern calculations.

In modern times some very remarkable showers have been observed. Among these one of the most noteworthy was that seen by Von Humboldt, the great scientific traveller, in South America. In the early morning of November 13, 1799, he witnessed thousands of fire-balls and shooting stars darting across the eastern sky from north to south. At first there was no spot in the sky as wide as three full moons, which was not full of them. Some were as big as Jupiter, some showered sparks, some burst, some as big as the Moon or half as big again went out without sparks, but had trains one-half or two-thirds the width of the Moon. This shower of shooting stars was visible partially in this country.

But on the night of November 12, 1833, there was another shower just as wonderful. This time people saw what Von Humboldt had not mentioned, that the tracks of the shooting stars seemed directed away from a point in the constellation Leo in the point of the Sickle. The sky, for hours, was alive with shooting stars coming much too fast to count. It is estimated that at the height of the shower they came at the rate of 200,000 per hour, or more than 50 per second. It was said they appeared as thick as snowflakes in the sky. Scientific men in this country, on the Continent, and in America, were deeply stirred. From this shower dates the beginning of meteoric astronomy.

Another brilliant display came 33 years later, on the night of November 13, 1866. At the Royal Observatory, Greenwich, 10,000 shooting stars were counted, and at Edinburgh 8,000 were registered. This shower was observed in all parts of Europe, and even as far as the most southern portion of Africa.

Some of us remember with what disappointment we stayed up all night, waiting for the return of the same great shower, in November, 1899, without seeing anything out of the ordinary. The 33-year interval between great November showers failed then. It was found immediately afterwards that we did not encounter the great stream owing to planetary perturbations, probably the attraction of Jupiter turning away the swarm from the earth's path before the return of 1899. Chinese and Arabian records trace the shower back to A.D. 902.

There are other dates on which great meteor showers have been observed. One of the most famous of meteor streams is the Perseid shower, named from the fact that the radiant point is situated

in the constellation Perseus. The Perseids are generally seen in large numbers about August 10 (St. Lawrence's Day); hence they are called in Ireland "the tears of St. Lawrence the Martyr," who was put to death by being broiled upon a gridiron.

The history of this shower can be traced back to A.D. 811.

There is an annual shower about April 20, with centre or radiant in Lyra, which Chinese records trace back to 687 B.C. Another takes place in the third week of November and radiates from Andromeda. It was very brilliant in 1872, and on November 27, 1885.

Some of the periodic showers are interesting, because their meteors seem to follow the orbits of certain comets. It is believed that the meteoric shower in Perseus is due to the disintegration of an ancient comet which moved in the same path. A comet, named Tuttle's, whose period of revolution is $13\frac{3}{4}$ years, and which appeared in 1858, belongs to this orbit. In the year 1866, Schiaparelli calculated the path of the Perseid meteors, and found that it was practically the same as that of the orbit of Tuttle's comet of 1862. The Leonid stream of meteors on November 12 and 13 is connected with Tempel's comet which appeared in 1866. Halley's comet has its meteors, which appear early in May, coming from the constellation Aquarius. The Orionids, October 18-26, may also be connected with Halley, but this is doubtful. Even though the orbit of this great comet passes 4 million miles from the earth, we get shooting stars almost every year. If the orbit came closer we would probably have a fine display. These great swarms of meteors are members of our Solar System.

One word in closing as to their height and velocity. If we have two or three good observations of a meteor's track among the stars by observers at known positions, it is a mere matter of trigonometry to work out just what was its true path in space; when and how high above the earth it appeared, and where it vanished. Such calculations show that meteors usually light up at a height of about 60 or 70 miles, and vanish at about 40 miles. Their velocity is very great, averaging 25 miles per second. This speed is half again as great as that wherewith the earth describes her orbit about the Sun. Moving with such a velocity, a body would pass from the earth to the Moon in $2\frac{3}{4}$ hours, or from Aberdeen to London in 20 seconds.

The shooting stars are comparatively small. We do not know just how big they are, but we can figure out how much energy they send out in the form of light. Assuming that their luminosity is comparable to that of artificial sources, we arrive at an estimate of their total energy, and, knowing their velocity, obtain their mass. In this way it can be shown that a bright shooting star is considerably smaller in size than an ordinary pebble.

CHAPTER XVII

THE BRIGHTNESS OF STARS AND THEIR DISTANCES

SINCE the time when men first looked intelligently upon the starry skies, they have doubtless wondered what these shining specks might be, at first with the vague questioning of the child in the nursery rhyme,

"Twinkle, twinkle, little star;
How I wonder what you are";

then, as knowledge grew, with gradually greater understanding.

It is a well-known fact that the stars are huge luminous orbs like the Sun, at enormous distances from each other. Widely as the stars appear to our eyes to differ in brightness, their real differences are still greater. Even if we select a number which appear to be of the same general degree of brightness, we find, when we try to measure their distances, that some are enormously more distant than others which seem to us equal to them in brightness.

In this chapter I shall try to show how great these differences are by naming a number of stars which include the brightest in the sky.

One of the brightest stars, not only to our eyes, but in reality, of which we know is Rigel, in the constellation Orion, which is 13½ thousand times as bright as the Sun; one of the faintest so far known is the feeble, distant companion of Alpha Centauri, the nearest star, which is one ten-thousandth part as bright as the Sun. Between these widely separated extremes

we know of thousands—in fact, millions—of stars of all degrees of brightness.

But what information can we gather in regard to these remote orbs of space? From the most recent investigations which have been made it seems probable that the whitest and hottest stars, like those in the belt of Orion, give out twenty times as much light per square mile as the Sun does. Stars like Sirius, a step lower in temperature and colour, may be seven or eight times the Sun's surface brightness; while yellow stars, like Procyon, are twice as bright as the Sun. Those resembling the Sun in colour and spectrum may be assumed to be similar also in surface brightness; but orange stars, like Arcturus, are probably about one-sixth the surface brightness of the Sun, while red stars, like Antares in the Scorpion, may fall as low as one-thirtieth or even lower. Fortified with these estimates, we may proceed to figure out how big some of the familiar stars are.

Let us commence with those in the constellation Scorpio, so well seen in the beginning of June at 11 p.m., looking direct south. The principal stars of this constellation are very distant and very bright. With the exception of Antares, the brightest star in the constellation, they are all white and hot stars. The brightest of these is at the end of the tail of the Scorpion, and is called Lambda Scorpii. It sends out about 1,500 times as much light as the Sun. As Lambda Scorpii is a very white star, we may estimate its surface brightness at about fifteen or twenty times that of the Sun, and its diameter ten times. The other conspicuous stars in the constellation are a little fainter and probably somewhat smaller, but they are all probably several million miles in diameter. The fiery red Antares, in the heart of the Scorpion,

is so named because its red colour makes it appear a true rival to the planet Mars, Ares being the Greek name for Mars. It is one of the largest we know, and it has been placed in the same class with Betelgeuse. Its light power surpasses the Sun 3,000 times. Its diameter is 270 million miles. This star is so vast that the whole orbit of the earth could be put inside it. Light occupies 250 years in coming to us from Antares.

When we speak of the distance of a star in light years, we mean the distance that light, travelling with a velocity of 186,000 miles per second, would cover in the course of one year.

The other conspicuous stars seen in June at 11 o'clock in the evening are:

(1) The golden yellow Arcturus, high up in the south-west. Its luminosity is 115 times that of the Sun, while its diameter is 17 million miles. Its distance from us is forty-three light years, or 2,750,000 times that of the Sun.

(2) The bluish-white Vega, almost overhead, is thirty-five light years distant. It gives out seventy times as much light as the Sun, and its diameter is 2,500,000 miles.

(3) Altair, white, below Vega, is situated between the east and south-east. It is fourteen and a half light years distant from our Solar System and is eight times as bright as the Sun, while its diameter is only one-half larger.

(4) Regulus, white, low down in the west, is 100 light years distant from us and gives out 250 times as much light as the Sun.

(5) Spica, bluish-white, low down in the south-west, is 230 light years distant from us and sends out 3,000 times as much light as the Sun.

(6) Capella, yellow, low down in the north, is fifty light years distant and eighty times as bright as the Sun, while its diameter is 8 million miles.

Two well-known winter stars are Procyon in Canis Minor, the "lesser dog," and Sirius in Canis Major, the "greater dog." Procyon is a little fainter, yellower, and cooler than the star Altair which has just been mentioned, but it is probably similar in bulk. Its distance is ten light years.

Sirius is the apparently brightest of all the stars in the heavens. From recent measurements which have been made, it has been found to be thirty times more brilliant than the Sun, three times as heavy, and twenty-seven times as large in volume. In addition to this, Sirius has a small companion which is only visible in large telescopes, and which goes round it once in forty-nine years. This small body causes irregularities in the motion of Sirius, and was thereby discovered, through calculation, about thirty years before it has ever been seen in a telescope. It is a star almost as white as Sirius. It is much hotter than the Sun, and weighs as much as the Sun does.

Sirius travels in the same direction as the five central stars in the Great Bear. These stars are journeying through space together, bound by the ties of universal attraction, travelling to a common but unknown destination.

There are several stars in the Greater Dog, which may well be called giants. Beta Canis Majoris, which, to the eye, seems so small compared with its neighbour Sirius, is 360 light years away, and 2,000 times more luminous than the Sun.

Another bright star in the constellation is Delta. It is nearly 600 light years distant, and emits 5,000 times as much light as the Sun.

Another group of bright stars is in the constellation Orion. They are displayed in their full effulgence during the winter evenings. It has long been known that these stars are remote and very brilliant objects. Such objects are most impressive when we consider, first, their immense bulk, great luminosity, and the extremely high temperature to which they owe their brilliancy; and, second, their past history and future duration.

The giant red star Betelgeuse is about 1,500 times brighter than our Sun, but because it is so far away it appears to us 100,000 million times fainter. Its distance from us is so great that its light takes 180 years to reach us, so that we who are living in 1932 actually see this star as it was 180 years ago. Its diameter is more than two and one-half times the distance of the earth from the Sun, or about 235 million miles. It is more than 270 times the diameter of our own Sun, and 21 million times its volume.

There are many red stars, such as Betelgeuse, Antares, and Arcturus, which present the evidences of youth. They have not yet risen to their greatest temperature, but are already extremely brilliant owing to their large diameter. There is every reason to believe that such stars live their lives at a much more rapid rate than our Sun, which appears to be in later life than they are. It is well past the maximum of temperature, but with still a long life of moderate activity before it.

In the northern part of Orion we find that Gamma, in the Giant's shoulder, is at a distance of 360 light years, and gives out 2,000 times as much light as the Sun. The neighbouring star Lambda is 450 light years distant, and, though not very conspicuous to the naked eye, is 500 times brighter than the Sun.

The three stars in the belt of Orion are respectively 300, 400, and 550 light years distant, and each of them emits 3,000 times as much light as the Sun. With many others in the vicinity, they belong to a cluster of white and hot stars which centres itself upon the great nebula of Orion, and is, therefore, called "the nebula group." The average distance of this group is 600 or 800 light years. Even those stars of the cluster which appear faint to the naked eye are huge suns, giving out from 1,000 to 4,000 times as much light as the Sun. Those gigantic stars have already been shining for hundreds of millions of years, while their future duration as light-givers, before they finally cool off to the point of extinction, is likely to run into thousands of millions of years.

But the leader of this starry host is the bright, sparkling, bluish-white star Rigel. Its luminosity is 13,000 times that of the Sun. It is not possible to realize what these figures actually mean. Perhaps the best idea can be obtained by those who are familiar with Rigel as a telescopic double star. There is a companion close to Rigel which, in a telescope, appears like a small speck of light alongside its dazzling primary, which exceeds it about 300 times more in brightness. Yet even this inconspicuous attendant is forty times as bright as the Sun and nearly twice as bright as Sirius. In examining the star with the spectroscope, it is found to belong to the earliest type of stars. It has been estimated that Rigel gives out twenty times as much light per square inch as the Sun does. If this estimate be correct, its surface must be over 600 times as great as that of the Sun, and its diameter about twenty-five times that of the Sun, or 22 million miles. This

would make its bulk 15,000 times as large as the Sun. These figures probably give us some idea of the nature of this gigantic ball of gas, fairly dense at the centre, but highly incandescent even to its very limit. In front of such a star, our Sun, so dazzling to us, would appear like a small dark spot, if viewed with a dark glass similar to what is used in observing sunspots.

To find stars smaller than the Sun we must look for them among the faint members. Take, for example, the well-known binary star 61 Cygni, which is one of the nearest—viz., 10 light years distant. When we speak of a binary star we mean a star that constitutes a separate system with a physical connection between its two members. The stars of this pair are about one-twentieth and one-fortieth as bright as the Sun. They are also orange-red in colour, and their surface brightness may be estimated at one-twentieth that of the Sun, which makes the diameter of the brighter companion about equal to that of the Sun, and the fainter one three-quarters as great.

Passing to still fainter stars, we may take another near one, called Barnard's star. It is 6 light years distant from us. It gives out only one two-thousandth part of the light that our Sun emits. This is a very red star, and its surface brightness is only one-fiftieth that of the Sun. This makes its diameter about 120,000 miles. Some of the near stars have faint companions which give but a very small fraction of the Sun's light. Such faint stars are not at all exceptional. There are dozens of them known to be within 50 light years of our Solar System. None of these small stars, however, can be seen without a telescope. Some of the stars

which are conspicuous to the naked eye are only a little larger than the Sun in actual diameter; others are much larger, especially the Giant red stars; but there are probably few that exceed the dimensions calculated for Antares in Scorpio and those in Orion and Canis Major.

CHAPTER XVIII

VARIABLE STARS AND NOVÆ

VARIABLE stars and Novæ are stars whose light does not remain constant. For more than 300 years variable stars have been objects of great interest and observation to astronomical observers. Up to the present more than 6,000 variables have been discovered. Variability is widespread among the stars. Novæ appear only in or near the place of the Milky Way, but variable stars are scattered over the entire heavens, and are found among stars of all magnitudes, from the first to the twentieth. The length of time that elapses between successive maxima or minima of brightness is called the period.

Much interest was aroused in the subject primarily through the investigations of two English astronomers, John Goodricke and Edward Pigott. They were the first to open the field of short-period variation of stars. These variables, with periods of a few hours to fifty days, have been responsible for much of the knowledge which we now have concerning the properties and ages of the stars, their interiors, their distances, and the extent of the universe.

Edward Pigott was the son of a surveyor who had a few small astronomical instruments, and had employed them to observe the planets and stars. It seems that the son inherited his love for astronomy from his father, and was accustomed to make observations at his own home. His knowledge of the heavens attracted to him John Goodricke, who is one

of the most extraordinary characters in the history of science. Born a deaf-mute, he received, nevertheless, a good education, and became especially proficient in mathematics.

In 1782, when he was only eighteen years of age, he commenced observations on the variable star Algol at the home of his friend Pigott. In a short time he had discovered its period of variation by comparing its brightness with that of the neighbouring stars. Its variation was small, only 1·2 magnitudes, which makes the difficulty of observation considerably greater than that of the variables of the type of Mira, where the variation is 5 or 6 magnitudes. He found the period to be 2 days 20 hours 49 minutes, which was much shorter than that of any variable known before.

In that early day when physical double stars were scarcely known, he boldly concluded that the light changes were the result of an eclipse of the star by a darker companion which was describing an orbit about it in such an unexpectedly short time. It was a hundred years before this remarkable conclusion was verified by Professor Vogel, who observed the star with the spectroscope and found that it was actually moving in an orbit in accordance with the theory.

Two years later, Goodricke discovered the variability of Delta Cephei with an even smaller range (0·7 magnitude) of variability, and deduced a period of 5 days 9 hours. He recognized it as a different kind of star, but he was not able to explain the cause of its variation, and we can do only slightly better to-day. In the same year he also observed Beta Lyræ, whose period is 12 days 22 hours and range 0·6 magnitude.

Eclipsing Stars

The eclipsing stars, of which Algol is the prototype, are not intrinsically variable at all, but are binary stars whose orbits happen to be so placed that the components eclipse each other at certain times when observed from the earth. They are always close together, and their periods are usually short, from a few hours to a few days. Study of the light and velocity changes of such stars makes it possible to determine their masses, densities, absolute dimensions, surface brightness, and the distances between them. These are the only stars for which these data may be directly calculated. About 300 eclipsing stars are known, most of which are found among the hottest and brightest stars. They probably represent the early stages of double-star existence, when the two stars have just been formed from a single body. They are often elongated towards each other by tidal effects, and in some cases may be actually in contact.

The Cepheids are known from Goodricke's star Delta Cephei, which was the first known and the brightest of its class. They are single stars of great intrinsic brightness, and are super-giants. Study of their light changes shows that they rise from minimum to maximum much more quickly than they fall from maximum to minimum. The variation is usually a little less than 1 magnitude, the maximum brightness being about twice that at minimum. The spectroscope shows that the surface is heaving up and down with the period of the stars' variation, and that changes of temperature are taking place. Due to some cause, as yet unknown, the gaseous body of

a star seems to have taken up a periodic pulsation of some kind, which may explain the action observed there. More than 500 Cepheid variables have been discovered in the globular clusters, where they are pulsating with a period of about twelve hours. These clusters are situated in different parts of the sky, at distances varying from 20,000 to 200,000 light years from the Sun.

It is very doubtful whether there are any stars which are absolutely constant in brightness. It appears that variation is a relative matter. Nearly all very red stars appear to vary slightly in an irregular way. Our Sun shows small changes in intensity of about 2 per cent., which appear, in general, to follow the sunspot activity in the eleven-year period with considerable irregularity. At certain times there are also fluctuations within a few days. The spots themselves, the faculæ, and the prominences, are constantly changing, and all affect, to a certain extent, the total amount of radiation emitted. Probably activities of a similar kind could be found in the atmospheres of all stars if we could get within observing distance. The Sun is the only star on which we can actually observe details of atmospheric activity. Owing to its proximity we see its surface as a disc of immense size, and, with the aid of the telescope, we can examine the changes that are taking place there. Sunspots are indicators of the presence of disturbances low down in the atmosphere of the Sun. They are generally accompanied by faculæ which are areas of intense activity and high temperature.

We shall now pass on to speak briefly of long-period variables ranging from 65 to nearly 800 days. The typical star of this class is the remarkable star

Mira. This was the first periodical variable star that was noted. In 1596 Fabricius, a Flemish clergyman, noticed that this red star was bright for a few months and then fell below the limit of visibility. He evidently thought it was a Nova. Its periodic character was not discovered till 1638. Continued observation showed that it returned to maxima quite visible to the naked eye in a period of 330 days, that it was visible about five months, and too faint to be seen for six months, and that its rise to maximum was nearly twice as rapid as its decline. Owing to its extraordinary behaviour it was called, Mira, "the Wonderful." No more appropriate name could have been given to this star, for it continues to show peculiarities which cannot be predicted and which are little understood. Its variations are somewhat uncertain, but they average about 6 magnitudes, or 250 fold increase from minimum to maximum light. Although it received its name largely owing to the surprise caused by its periodic character and its great range of brightness, its behaviour, as studied by the spectroscope, has been even more wonderful, and it has perplexed observers since its spectrum was first observed more than forty years ago.

There are several facts in connection with the star and others of its class which are of special interest. Its apparent diameter is the largest thus far measured with the interferometer, and its real diameter—260 million miles—is second only to that of the red star Antares in Scorpio. Were it brought to our Solar System and set in the place of the Sun, its boundaries would extend beyond the orbit of the planet Mars, and the earth, in its annual motion, would describe its orbit not much more than one-

half the distance from the centre to the circumference. The mass has not been directly determined, but it is probably about five or ten times that of the Sun. This low value means that we have an exceedingly large body with comparatively small mass, and the density comes out very low.

Mira and the other long-period variables are the coolest stars known. The temperatures of the regions which we see vary with the brightness of the star from 1,600 degrees to 2,500 degrees Centigrade absolute. Its red colour is easily noticed by the eye. A limit of stellar temperature appears to be set at this point below which stars do not emit sufficient light to make their presence known to us. The temperature is so low that molecules of titanium oxide are able to form in the upper atmosphere. As shown by the bands in the spectrum, these molecules absorb some of the light from the interior, and are partly responsible for the great light changes observed. As the star grows colder, this absorption increases and so helps to diminish the light.

Radial velocity measures also indicate that the star expands and contracts during its period to the extent of 20 per cent. of its radius, or about 30 million miles. The cause of this pulsation is not known, but it is sufficient to produce a distinct change in the effective temperature and a corresponding light variation. There are more than a thousand variables of this type whose activities take place in periods of about a year.

And now a few words in closing about new stars which suddenly flame forth. The first scientific record of variation among the stars seems to be that regarding the appearance of Tycho Brahe's new star or Nova in 1572. This bright Nova appeared

in the constellation Cassiopeia at a point where no star had been known before. It was as brilliant as Venus at its brightest, and could be seen in the daytime. After a few months it disappeared from view, because there were no telescopes at that time to follow it farther. Owing to the lack of accurate observation of its position, it cannot with certainty be located at the present time; but it seems identical with a faint star of the 14th magnitude. If so, it has decreased in brightness at least 17 magnitudes, or 6 million times, since its historic and record-breaking outburst.

Many of us recall Nova Aquilæ, which was discovered on June 8, 1918, as a 1st magnitude star. Photographs show that for thirty years previous it was an unknown and inconspicuous star of the 11th magnitude in the Milky Way. Sometime about June 6 of that year the most interesting period of its history took place. The next day it had increased in brightness one hundred fold, and was doubling its brightness in the short space of one hour. On the following evening, June 8, having increased another hundred fold, it was independently discovered within a few hours after it rose above the eastern horizon by a number of astronomers and amateurs in Europe and America. The outburst reached its maximum on June 10, when the star was equal to Canopus in brilliancy, being second only to Sirius itself.

To know the precise time of the outburst, about 1,000 years must be subtracted from the date of its appearance, for the star is so far away that it takes about that time for its light to reach us.

After its maximum, the decline set in, but at a much slower rate than the rise. What was gained

in brightness in the two days before maximum was lost in 200 days, and, after that, the decline was even slower. It did not return to normal intensity for two years after its four days of dissipation.

The spectrum showed remarkable changes of a character seen only in Novæ. At maximum, and probably before, it resembled the spectrum of a hot massive star, but with the lines much displaced, showing that the star was expanding at a swift speed of more than 1,000 miles a second. Notwithstanding this tremendous expansion to a million times its original volume, the high temperature of more than 10,000 degrees was maintained, so that the surface brightness did not change much until after maximum. The increase in light seems to have been due, largely, to an increase in the dimensions of the star itself. The outburst was, in effect, an explosion.

Soon after maximum a gaseous shell was formed, which has continued to increase in diameter for nine years up to the present time. It now forms a ring of gas about the star similar to the ring nebula in Lyra, but about one-fourth its apparent size.

Whatever may be the cause of the sudden outburst, we have observed in this case the actual formation of a ring or planetary nebula in a very small space of time. A most astonishing phenomenon has taken place before our eyes. The processes of celestial evolution have become a sight of activity and change. As the shell of gas is thrown off from the star at a speed of 400 miles a second, the character of its radiation changes quickly. Mainly the lightest elements are thrown out of the star, and the rays which we actually see are those proceeding from hydrogen, helium, and nebulium atoms. This latter is a hitherto unknown gas which Bowen has

recently shown to be merely oxygen and nitrogen, the elements so well-known in our atmosphere. They were not recognized previously, because such rays could not be produced in terrestrial laboratories.

The cause of Novæ outbursts, which are the most violent of all stellar activities, is still uncertain. We know much of the results of the explosion, but the underlying cause can only be conjectured.

One explanation suggested by some is that the sudden appearance is caused by two suns colliding, or passing quite near each other, with resulting violent outbursts due to tidal disturbances. This theory is objected to on the ground that Novæ return within a few years to their former level of brightness, and also that collisions cannot be so frequent as Novæ are observed, owing to the vast distances separating the stars.

A second explanation is, that the sudden outburst of light is produced by a star running into a nebula or huge mass of nebulous matter. This theory was first propounded by Dr. Seeliger and W. H. S. Monck independently. Regarding this theory, Mr. Peter Doig, F.R.A.S., says in his admirable volume, "Stellar Astronomy," p. 114: "The displaced lines are on this theory due to expanding and cooling gases moving outwards, successive streams of matter accounting for the double, or sometimes triple nature of the lines. Dark lines would alternate with bright bands according as the stream was pointing towards the observer or not. Two objections are to be found, in the suddenness of the outburst and the brevity of duration, which would seem to entail an abrupt boundary for the nebulosity, and a very small extent for it. There is, however, on the other hand, evidence that novæ appear at or near the edges of

regions of the Milky Way occupied by obscuring clouds and also the appearance of a disc of nebulous matter surrounding the star, both of which seem to be in support of the hypothesis; and the abruptness of outline of the dark nebulæ is a fairly conspicuous feature of these objects."

A belief is now gaining ground that some great internal catastrophe causes the star to expand suddenly. This might explain, for instance, the 60,000 fold increase of the light given out within two days by the Nova Persei in 1901. In explanation of this popular theory, Mr. Doig says in his "Stellar Astronomy," pp. 114-115: "There has been recently a tendency to favour an explanation of a nova as due to a development of energy somewhere beneath a star's surface which heats the material so highly as to cause violent expansion into space in all directions at speeds beyond the power of gravitational control. For a few days the density of the expanding gas is great enough to give a continuous spectrum. The light increases tremendously, and as the gas becomes more tenuous the spectrum becomes discontinuous, a moving gaseous shell being formed which produces absorption lines displaced towards the violet where it comes between the star and the observer, and bright bands from the other parts which have motions in all directions with respect to the observer, varying from zero to approaching and receding. It is suggested that the source of the energy in this hypothesis is sub-atomic, its release being precipitated either by some internal condition in the star or perhaps, as suggested by W. H. Pickering, by collision with a wandering body of comparatively small dimensions and relative frequency in space. Later on, the main mass,

highly heated by the cataclysm, subsides, at first irregularly, but later more gradually, into a hot star of the Wolf-Rayet type, surrounded perhaps after a few decades by a planetary nebula. The occurrence of the novæ in galactic regions, especially those marked by the presence of dark clouds, may be due to a relative frequency in such regions of the small wandering bodies, collision with which acts, so to speak, as a sort of detonator releasing the sub-atomic energy of the star." One word more: we must not suppose that these great stellar catastrophes actually occurred on the same day on which they were discovered. The light by which observers saw them had been on their way certainly for decades, probably for centuries; and it is more likely than not that the terrific outbursts which became visible on earth in recent years, really took place before the Reformation period.

CHAPTER XIX

STAR CLUSTERS AND THEIR DISTANCES

In different parts of the heavens the stars seem to be classed into more or less conspicuous clusters. Most of these are visible only with the telescope. But here and there we find one in which the individual stars are so bright and so widely scattered in the sky that the character of the cluster can be recognized by the unaided eye. Astronomers of ancient times recognized several of these clusters, and gave them names which have come down to us and are still in use.

The most conspicuous and the most notable cluster of all is doubtless the Pleiades, which, from the brightness of the stars and their close association, attracts the attention of the most casual observer. Not far away, and also in the constellation Taurus, is the more scattered group, called the Hyades—the "rainy stars"—because their appearance marked the beginning of the rainy and stormy season in Greek waters. Farther east in the sky, in the constellation Cancer, is a hazy spot known to the ancients as Præsepe, meaning a "sheep-fold." The naked eye just fails in this cluster to recognize the individual stars, but a small opera glass shows them plainly. Eastward again, beyond Leo and to the north, is Coma Berenices, containing a number of faint stars.

When the modern astronomer comes to consider these star groups, the first question he asks is, naturally, "Are the stars of these clusters actually

close together in space and connected in some way, or are we dealing with a mere accidental clustering of stars unrelated to each other, some near, some remote, and looking close together in the heavens only because they happen to be nearly in line with one another?" For a dense cluster like the Pleiades, calculation confirms that it is incredible that so many bright stars should, by pure accident, be packed into so small a portion of space with the entire expanse of the sky available.

It has long been known that about forty stars in the Hyades and the surrounding region are moving across the sky in much the same direction and at nearly the same speed. This discovery puts it beyond doubt that the Hyades stars also are a real cluster which now are fairly close neighbours in space, and have been so in the past for an unlimited period of time.

It is also apparent, on careful study, that the motions of these stars in the heavens are not quite in parallel lines, but that they converge toward a fixed point, about 10 degrees east of the bright ruddy star Betelgeuse; so that if it were possible for us to observe the cluster for ages of time, we should see it approach this point in the sky, and apparently shrink together in doing so. This must evidently be an effect of perspective, due to a gradual recession of the cluster from the Sun. Spectroscopic observations show that these stars are really receding, and all at the same velocity—another proof of physical connection. By combining what we know of the apparent rate of motion of the cluster in the heavens and the actual speed in miles per second, its distance is found to be about 140 light years.

All the naked eye stars in this part of Taurus, however, do not really belong to the cluster—for example, Aldebaran, the brightest of all, is moving across the heavens in quite another direction, and is very much nearer to us than the stars in the cluster. But these unconnected or outside stars can be recognized at once by the fact that their motions do not correspond with that of the cluster.

A similar community of motion exists among the stars in the Pleiades, Præsepe, and Coma Berenices. It seems, therefore, that these groups are real clusters. The brighter stars in the Præsepe cluster are all receding from the Sun at the same speed, and this speed is nearly the same as in the case of the Hyades, while the proper motion of the group, though small, is directed nearly toward the point in the sky toward which that cluster is moving. The two clusters, though 60 degrees apart in the heavens, are actually moving in parallel lines in space, and, in the course of millions of years, the inhabitants of the earth may see them drawing closer and closer to one another in the sky, shrinking in size and growing fainter as they go. Knowing this point, it becomes possible to calculate the present distance of the Præsepe group. With the best data available, this works out at 450 light years.

It is a well-known fact that there is a singular relation between the brightness of the stars in the Hyades and their colours and spectral types. Stars in this cluster which are of the same real brightness as the Sun are very similar to the Sun in spectrum. Those fainter than the Sun are redder and more advanced in spectral type, while most of the brightest stars in the cluster are white, almost like Sirius in

spectrum, and are, on the average, about forty times as bright as the Sun. There are, however, four bright stars belonging to the Hyades, which are redder in colour and have spectra like Arcturus. These red giants are, on the average, about fifty times as bright as the Sun. In the Præsepe cluster only the brighter stars can be observed—the rest are too faint—but among these the same situation is found. Most of the real members of the cluster are white, while a few, equal in average brightness to the others, are reddish. The brightest individual stars give out from thirty to fifty times as much light as the Sun. There are about one hundred which are brighter than the Sun, and some twenty of these are ten times brighter. The faintest stars which have been found in the cluster must be but feebly luminous. The brighter stars in Coma Berenices show a similar distribution in colour and spectrum. The distance of the cluster is about 350 light years, while that of the Pleiades is probably about the same. Several thousands of stars can be photographed in this cluster, but the great majority of them are faint and do not belong to the cluster. It is found that the number of such faint stars is really less in the region of the cluster than in the area immediately surrounding it. This is probably due to the fact that a faintly luminous nebulosity extends over most of the cluster and cuts off some of the light of the stars that are situated beyond it.

We shall now pass on to speak of globular clusters. It has long been known that globular clusters are not uniformly distributed over the sky; nor do they, like most other celestial objects, congregate towards the plane of the Milky Way.

Instead, they are almost confined to one-half of the celestial sphere, with its centre in the constellation Scorpio, which contains more than sixty such clusters; while in the opposite half of the heavens there are less than half a dozen. The nearest of the globular clusters—Omega Centauri and 47 Toucani; both in the southern hemisphere—are at about equal distances of 16,000 light years. Each of these clusters is easily visible to the naked eye, though not in our latitude, and the total light given out by all the stars of either cluster must be something like half a million times the light of the Sun. The remotest cluster so far investigated—a faint object bearing the number 7002 in the general catalogue of clusters and nebulæ—is at the enormous distance of about 160,000 light years.

In the constellation Hercules may be seen a little hazy speck of light. With a telescope of 10 inches aperture, this mass is resolved into a great globular cluster of stars, very faint individually, but so exceedingly numerous as to present a magnificent spectacle. With the greatest telescopes the cluster is a most impressive object, the whole field of view being scattered thickly with countless points of light. Photographs of long exposure, such as have been obtained with some of the largest reflectors, reveal a globular aggregation, densest at the centre, containing about 50,000 stars as bright as the 21st magnitude. Like the nearer stars the members of the cluster differ in colour. Some of them are as blue as the stars in Orion, while others are as red as Aldebaran or Antares, and all intermediate colours are represented. It is found that the brightest stars are all red or orange. On passing to those a little fainter many white stars are found, while

among those still fainter, of the 15th and 16th magnitude, all the stars are white or yellowish in colour.

Among the stars whose distances we can measure and whose real brightness we can calculate it is found that some of the brightest are red—for example, Antares, which is, in reality, about 3,000 times as bright as the Sun. Among the stars of brightness 20 to 100 times that of the Sun, however, the great majority are white; and those of the Sun's brightness, like the Sun itself, are yellow; while the still fainter ones are orange and red. It is only among the stars of greatest real luminosity 100 times that of the Sun that stars of the same colour may be found. This makes it very probable that the brighter stars in the Hercules cluster which show a similar wide range in colour are also objects of great brightness, and that those somewhat fainter stars which are almost all white are comparable to Sirius and Vega. If this be true, the distance of the cluster must be enormous to reduce such brilliant stars to their apparent inconspicuousness. Harlow Shapley estimates that the distance must be of the order of 30,000 light years. In all probability the individual stars are moving each in its own orbit around the centre of the swarm as a whole. If this be so, it would take more than a million years to complete one single circuit; so it is not surprising that no relative motion has been detected among the stars of the cluster since the accurate photographs were obtained. Calculating the whole position in space of the 69 clusters definitely recognized as globular, Harlow Shapley finds that they themselves form a huge flattened cluster, probably 200,000 light years in diameter and about a quarter of that in thick-

CLUSTER M13 HERCULIS, APRIL 25, 1901.

(Photograph by G. W. Ritchey and F. R. Sullivan, Yerkes Observatory.)

SPIRAL NEBULA M64 COMÆ BERENICIS, MAY 5-8, 1910.

(Photograph by G. W. Ritchey, Mount Wilson Observatory.)

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GREAT COMET OF 1858.

THE GREAT NEBULA IN ANDROMEDA.

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ness. The diametral plane of this great system coincides with the plane of the Milky Way, very few clusters being more than 50,000 light years distant from this plane. The centre of the system is, apparently, about 50,000 light years distant from the Sun, in the direction of the great star clouds in Sagittarius.

I shall just mention one more globular cluster. It is in the northern constellation Canes Venatici. It is estimated that there are 30,000 stars in the cluster. Some of them are as large as the Sun, while others are comparable in brightness with Canopus and Rigel and send out 2,000 times as much light as the Sun. Its distance from our Solar System is estimated at 45,000 light years. Thousands of variable stars have been found in these globular clusters. These stars are variables of the Cepheid class, and are remarkable for the uniformity of their periods, their range of variation, and their brightness. It is worth noting that one in seven among the brightest of the cluster in Canes Venatici is variable. At maximum the light is about the 14th magnitude, while at minimum it is fainter than the 16th magnitude. The whole period of variation from one light maximum to the next is about thirteen hours. The Cepheids have been employed by Shapley as one means of determining the distance of the globular clusters, and, indirectly, the size of the stellar system.

These very remarkable facts indicate strongly that the globular clusters, after all, are really members of the same enormous system as the stars of the Milky Way, and that the whole system is enormously vaster than anyone had previously dared to imagine. Near the central plane—that is, within 4,000 light years

of it—there appear to be no globular clusters; and it is just within this central region that there lie all the stars visible to the naked eye, almost all the brighter telescopic stars and all the gaseous nebulæ.

CHAPTER XX

THE MILKY WAY AND ITS DARK MARKINGS

As we stand on a clear moonless evening in autumn and face the south-west, we behold one of the most marvellous sights in the heavens. It is the Milky Way, which is, after all, the principal feature of an autumn and winter moonless sky. Following its grand arch from the northern to the southern horizon, we notice that in the north, in Auriga, Perseus, and Cassiopeia, it is relatively faint; that it becomes much brighter overhead, in Cygnus; while in the south, from Aquila, Scorpio, and Sagittarius, but particularly in the last constellation, it is very bright and full of clouds and patches of light.

There is also a second and fainter shining stream parallel to it. As we mark the two back to the northward it is worthy of observation that they run together almost overhead, and that the northern Milky Way, though irregular in outline, does not show a double structure. If at some other season of the year we study the part of the Galaxy which is now below our horizon, we observe that it consists of a single stream of irregular breadth, relatively faint, north of the equator in Auriga and Gemini; then brightening slightly, but remaining single in the southern horizon. In the southern latitudes, where the part of the Milky Way which is invisible to us can be viewed, it is found that on this side of the heavens also it becomes very bright. Though in

Orion and Canis Major it is relatively faint, below them it brightens up to a large degree, and this luminous region extends on through Centaurus and the Southern Cross until it joins up with the prominent region in Sagittarius. The two branches of the great stream of light which are lost below our horizon in Sagittarius remain separate for some distance in the southern sky, but they become one again near the Southern Cross. With regard to the Milky Way as a whole, there are two striking facts: first, it is considerably brighter on one side of the celestial sphere than in the opposite region; second, it is separated into two for about one-third of its whole extent, this division happening on the side of the sky where it is brightest. When it is viewed from southern latitudes, their great superiority to the northern parts is quite evident. It appears much brighter in the southern sky than in the northern because we are nowhere near the centre of the universe of stars—in fact, it seems from present evidence as though we were well out towards the side. Consequently, when we look towards the centre we see a great many more stars than when we look away from it, and the Milky Way appears correspondingly brighter. This important fact was first clearly brought out by Harlow Shapley's remarkable investigations on the globular clusters which indicate that the centre lies in the general direction of Sagittarius.

Rotation of the Milky Way System

As the result of investigations made by some eminent astronomers regarding the motions of certain types of remote stars, there is every reason to

believe that the Milky Way is rotating in its plane with great velocity, the speeds of the stars decreasing from the centre outwards.

In a suggestive article written by Mr. Peter Doig, which appeared in a recent number of the *British Astronomical Journal*, mention is made of this fact: "The centre about which this rotation is taking place is in exactly the same direction and at about the same distance away from us as is suggested by study of the distribution of the stars of the galactic system and also by the disposition in space of the surrounding globular clusters. The rotational velocity of the stars in the Sun's neighbourhood is found to be about 200 miles per second, with a period of rotation of nearly two hundred million years, which would require a central controlling mass of the order of two hundred thousand million times that of the sun! Strong support is given to these conclusions by consideration of the radial velocities of the globular clusters." "The thousands of spiral and elliptical nebulæ, situated at distances from us varying from about half a million light years upwards, show by their forms and also by spectroscopic measurements of internal radial velocities that they rotate, thus strengthening the belief in a similar movement for our own system."

Dark Markings

Between the two branches of the Milky Way the sky is dark. On a very clear evening when the sky overhead appears to be powdered with minute points, several of these dark regions may be viewed. One which is worthy of special mention lies to the west and north of Sagittarius, where, on the edge of the

bright star clouds, there is a dark region several degrees in length, from which fairly dark lanes run westward; one lies towards the red star Antares in Scorpio, while the other is several degrees higher up.

Another is found in Cygnus where one of the bright regions of the northern Milky Way is crossed by a wide dark lane, which suggests that the sky is obscured by a strip of cloud.

Another and even more notable dark region is found near the Southern Cross, and looks so black that it has been known to navigators for more than a century as the "Coal-Sack."

The real extent and nature of these dark markings in the sky, however, is disclosed only by photography. Photographs show that the sky is full of dark markings. More than 1,000 of these objects have been catalogued. Some of them are large, many of them are small, while others are long, narrow, and crooked.

It is generally supposed that these dark markings are not holes in the star clouds of the Milky Way through which we see the dark depths of space, but real clouds of obscuring matter between us and the Milky Way, which hide it, and in some places blot it out from the view of our instruments. The reality of this obscuration is observable in the case of the darkest markings, which are situated between Sagitarrius and Scorpio in the southern part of Ophiuchus. In this region the stars appear to be obliterated. As these obscured regions are permanent features of the sky, they are undoubtedly produced by something out among the stars. In some cases they are connected with regions of diffused visible nebulosity. We have a remarkable

STAR CLOUD IN SAGITTARIUS.

(*Cape Colony Observatory.*)

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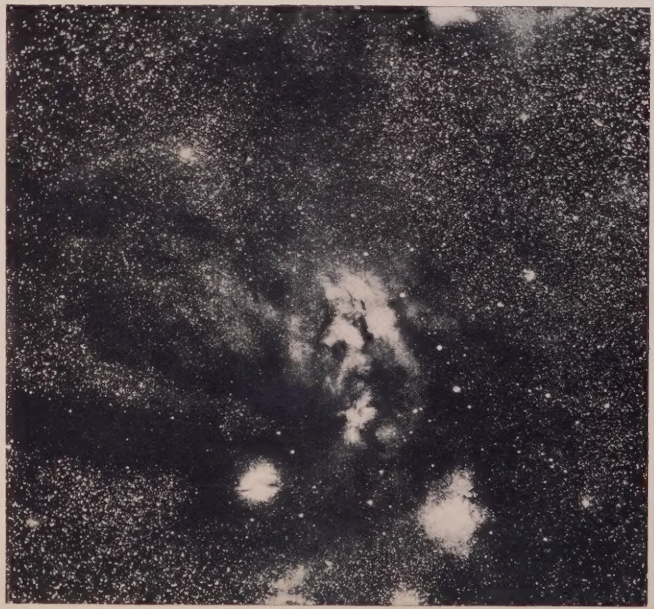

REGION NEAR RHO OPHIUCHI.

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instance of this in the dark lanes in Ophiuchus. They run up to the big patches of faint nebulosity which surround the star Rho Ophiuchi in such a way that the bright nebula is just a portion of the dark region which is made to shine for some reason connected with the presence of the stars about which the luminosity is condensed. This proves that the nebulæ, both bright and dark, are on the whole at the same distance as these stars. The obscuring clouds in Ophiuchus are estimated at a distance of about 500 light years. In one square degree in the obscured area near Rho Ophiuchi, only 350 stars have been counted. Just beyond the obscured area in Ophiuchus, five to ten thousand stars are found in one square degree, as against 350 in the darkest part.

Another conspicuous group of dark patches seems to be connected with the brilliant stars in Orion and the great nebula there. It is situated from us at a distance of 650 light years.

Another such group is found in Taurus. Its distance has been estimated at about 350 light years. These three great obscuring clouds are practically near us in comparison with the star clouds of the Milky Way, whose distance is estimated at thousands of light years. There are, however, many other and more remote dark clouds which appear smaller owing to their immense distance.

As to the real nature of these clouds it is evident that they are great masses of dust particles with a relatively small amount of gas. These clouds of cosmic dust mixed with gas are the largest objects known. The huge masses in Ophiuchus are estimated at 70 light years in length and 10 light

years in width. Those in Orion are probably larger, while the cloud in Taurus is estimated at 200 light years. Much if not all of the dark lane which runs down the Milky Way and separates it in two portions for nearly one-third of the circuit of the sky may be accounted for by similar dark matter hiding from our view part of the stellar universe. The extent of such a cloud mass must be reckoned at several thousand light years.

We must now mention briefly the size of the Milky Way, the number of stars estimated, and its distance. The number of stars which compose our Milky Way is estimated at about 30,000 millions. Of that immense number the distances of only a few thousand are known. I think we may safely affirm that most of the 30,000 millions of stars are, on the average, similar to those near neighbours whose distances have been determined. These distances give us a great deal of interesting information regarding the average intrinsic brightness, mass, and temperature of stars in general.

In our observations of the Milky Way star clouds we must remember that every star is a sun, and our Sun is an average star. The millions of minute points in the Galaxy are suns whose mass, size, and brightness are similar to our Sun. Were you to point to one minute star of the Galaxy in a photograph, it would probably be equal to our Sun in luminosity and size—that is, its diameter would be nearly one million miles and its mass expressed in tons would be two followed by twenty-seven ciphers. Were you to obliterate one of those miniature suns in the photograph, you would have put out of existence a sun. Were our Sun with its planets and satellites removed to this enormous distance, there

would be added only one more spot to the vast number of stars. Photographs and star counts confirm the fact that the stars are very much more numerous in that faint band of light than in any other part of the heavens. Photographs have been taken of dense star clouds in the Milky Way which disclose at least eighty thousand stars in an area the size of the full Moon, while there are seen only a few hundred in a similar area some distance from the Galaxy.

As to its form, it may be described as a very flattened disc similar in shape to a reading glass or a thick watch. Its size is estimated at about 200,000 light years in diameter and 50,000 light years in thickness. We infer this from Shapley's estimates of the distances of the globular star clusters which mark out and surround the Milky Way System.

More important than this new survey in scientific thought is its spiritual effect. Walt Whitman said: "The hair on the back of my hand is miracle enough for me." There are as great marvels in the substructure of the atom or in the chemistry of the living cell as in the Milky Way. My own deliberately formed opinion is that such an enormous universe must have divinity in it and over it. We must not assume for a moment that it is purely materialistic, the result of the chance sequence of self-created forces. But whatever our standpoint, the influence of astronomical knowledge is assuredly towards the exaltation of the mind. Whatever our place and purpose in this mighty universe, whatever may be our school of belief, all modern thought has been changed and enriched through the knowledge that we are all members of an organism so marvellous, so inconceivably great, that we cannot do otherwise than apply to it the adjective Divine.

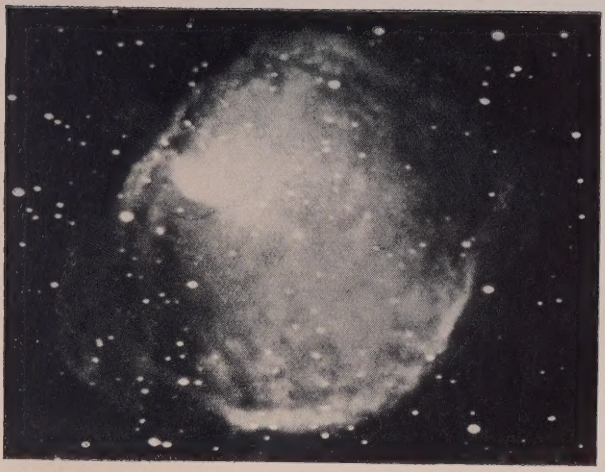
CHAPTER XXI

SPIRAL NEBULÆ

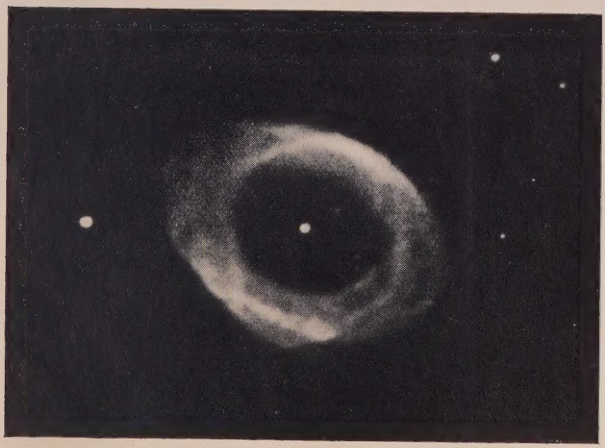
The history of scientific discovery supplies us with many instances where men with an extraordinary gift of intuition have looked forward from scanty data and have glimpsed truths which have been amply confirmed only after many years had passed away.

Sir William Herschel was singularly fortunate in this respect. From the proper motions of a few stars he determined the direction of the Sun's movement almost as correctly, due to a selection of stars for the purpose, as far more fully worked out present-day investigations. He observed that the star clusters which appeared nebulous in structure in smaller telescopes and with lower powers were resolved into stars with larger instruments and higher powers. From this he inferred that many of the nebulæ could be resolved into stars by applying high magnifying power and that the nebulæ were separate universes, a theory which had been earlier suggested on philosophical grounds by Kant, Lambert, and others. From their appearance in the telescope he excluded a few as distinctly gaseous and irresolvable.

This opinion held its ground for many years. Then came the results of spectroscopic analysis showing that many nebulæ, those which are classified as diffuse or planetary, are of gaseous constitution and cannot be resolved into stars. The spiral nebulæ, although exhibiting a different type of



DUMB-BELL NEBULA, JULY 31, 1899.
(Lick Observatory, California.)



ANNULAR NEBULA, LYRA, SEPTEMBER 17, 1910.
(Mount Wilson Observatory, California.)

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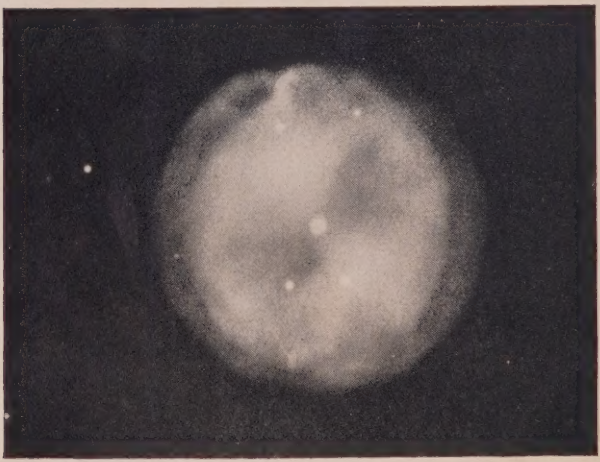
CRAB NEBULA, TAURUS, OCTOBER 13, 1909.
(Mount Wilson Observatory, California.)



OWL NEBULA, URSA MAJOR, FEBRUARY 9, 1910.
(Mount Wilson Observatory, California.)

spectrum, were, in most theories, practically included with the known gaseous nebulæ.

We have now, as far as the spiral nebulæ are concerned, returned to the fundamental principle of Herschel's inference; and the theory to which much recent evidence is pointing is that these magnificent objects are separate galaxies or "Island Universes," to employ the expressive and appropriate phrase coined by Humboldt.

By means of direct observations on the nearer and brighter stars, and by applying statistical methods to large clusters of the fainter or more distant stars, the Milky Way, which forms our own stellar universe, is supposed to contain not less than 30,000 millions of suns. Our Sun, a comparatively inconspicuous unit, is situated about 50,000 light years from the centre of Sagittarius. This Galaxy is not even approximately spherical in outline, but shaped like a lens or thick watch. The actual dimensions are about 50,000 light years in thickness and 200,000 light years in diameter.

Of the three classes of nebulæ observed, two—the diffuse nebulosities and the planetary nebulæ—are typically a galactic phenomenon as regards their apparent distribution in space, and are seldom found at any distance from the plane of our Milky Way. With the exception of certain diffuse nebulosities whose light is apparently a reflection phenomenon from bright stars involved within the nebulæ, both these types are of gaseous constitution, showing a characteristic bright-line spectrum.

Under the first division we have the well-known nebula in Orion. It is found to be of a gaseous nature and in a state of youth. This nebula is at a distance from us of 600 or 700 light years and

the diameter of the bright central part is 10 light years. It appears that different parts of it are coming towards us or receding from us at speeds which run up to 7 or 8 kilometres per second in either direction.

There are also the planetary nebulæ. They appear in a small telescope as roundish or oval in shape and with sharply depressed edges, and hence appear like a planet's disc. For this reason they have received the name of "Planetary nebulæ." Photography shows that most of them have central stars or nuclei, similar to the "Ring nebula" in Lyra, and that the outer nebulosity is brighter at the edge than near the middle. These central stars are probably very hot. Their spectra confirm this, as they belong to Class O, which contains the hottest stars of all. It has been found by Dr. Hubble that the diffuse gaseous nebulæ are associated with hot stars of the next cooler type—Class B—with a surface temperature of more than 20,000 degrees Centigrade. Many of the Planetaries have outer appendages on each side. Some are large objects, several minutes of arc in diameter, such as the Crab nebula near the 3rd magnitude star Zeta Tauri, which has curved filaments not unlike the claw of a crab; the Dumb-Bell nebula in Vulpecula, consisting of two oval masses connected by a ligament; and the Owl nebula, near Beta Ursæ Majoris, which has two darker spots looking like eyes.

The Planetary nebulæ show internal motions, probably due to rotation. The rates of motion vary from 3 to 6 miles per second. Besides these internal motions the Planetaries are moving bodily in space with high velocities at the rate of about 20 miles per second. Unlike the spiral nebulæ

the Planetaries are rare, not more than 150 being known in the entire sky; while their distances are, on the average, 700 light years.

Differing fundamentally from the galactic gaseous nebulæ in form and distribution, we find a very large number of nebulæ predominantly spiral in structure.

The following prominent points must be considered in any adequate theory of the spiral nebulæ: First, in apparent size the spirals range from minute spots just distinguishable on the photographic plate to gigantic spirals like the great nebula in Andromeda, which covers an area four times greater than that subtended by the full Moon. Second, prior to the application of photographic methods fewer than 10,000 nebulæ of all classes had been observed visually. One of the first results deduced by the late Professor Keeler from the programme of nebular photography was the fact that large numbers of small spirals are within reach of modern powerful reflecting telescopes. He estimated their total number at 120,000 early in the course of this programme and before plates of many regions were accessible. Professor Curtis made a count of the small nebulæ on all available regions taken at the Lick Observatory for twenty-five years, and from these counts he estimated that there are at least 722,000 spiral nebulæ accessible with large reflectors. Third, the most unaccountable feature of the spiral nebulæ is found in their peculiar distribution. They are seldom seen in the Milky Way. They seem rather to avoid this particular area, though they are usually found not far from its poles where there is a scarcity of stars. Fourth, an interesting point worthy of note is that spirals show a continuous spectrum

broken by absorption lines. A few spirals exhibit bright-line spectra in addition. A fifth point is that the speed of spirals through space is prodigious, being, on the mean, 500 miles per second, always away from the Sun. More than 200,000 of this group have now been recorded.

The speeds of approach and recession of some of the spirals have been measured by astronomers, and as the result of their spectroscopic observations it is found that in some cases they reach an enormous velocity of thousands of miles per second. Not one of the so-called "run-away" stars has a velocity approaching to anything like this.

On the older theory that the spirals are a part of our own Galaxy it is impossible to harmonize certain features of the data thus far presented. If this theory be true, their grouping near the galactic poles, inasmuch as all evidence points to a flattened or disc form for our Galaxy, would indicate that they are comparatively near us. In that case we should inevitably have detected in this class of objects proper motions of the same order of magnitude as those found for the stars at corresponding distances. Such proper motions are the more to be expected owing to the fact that the average space velocity of the spirals is many times that of the stars.

Professor Curtis repeated all the earlier plates of Keeler's nebular programme and was unable to find certain evidence of either translation or rotation in these objects in an average time interval of thirteen years. Their form and the evidence of the spectroscope show, however, that they are in rotation. Knowing that their space velocities are high, the

GREAT NEBULA IN ORION, OCTOBER 19, 1901.

(Photograph by G. W. Ritchey and F. G. Pease, Yerkes Observatory.)

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SPIRAL NEBULA M101 URSÆ MAJORIS,
MARCH 10-11, 1910.

(*Photograph by G. W. Ritchey, Mount Wilson Observatory.*)

Facing p. 165

failure to detect any certain evidence of cross-motion proves that these objects must be very remote, probably of the order of several millions of light years. From these facts, and from the evidence of the spectroscope, the Island Universe theory is given a certain measure of credibility.

We shall now conclude this chapter by mentioning a few facts regarding the "Queen of nebulæ." Only photography reveals the great spiral extensions which make this one of the most magnificent objects in the heavens, but even without these it is an impressive object. There is every reason to believe that the Andromeda nebula is a separate universe of stars. Dr. Hubble's latest data make the distance 870,000 light years and the extreme diameter 45,000 light years. Its mass is estimated at hundreds of millions of times that of our Sun, and its intrinsic brightness not far from one one-hundredth that of our entire galactic system. If formed on the same pattern as our Galaxy—and numerous types of observations show a close analogy—the Andromeda nebula must be a system smaller than our own, but containing hundreds of millions of suns comparable in brightness with any which we know in the universe of stars by which we are surrounded.

There are two other spirals whose distances can be measured or estimated. The first, Messier 33 in the constellation Triangulum. It is fainter and more open than the "Queen of nebulæ" and appears to be a little nearer—850,000 light years. Messier 101 in Ursa Major shows faint variables, and Hubble's estimate of its distance is fully 1 million light years.

These nebulæ, however, are only three of a vast

number of similar objects, smaller and doubtless much more distant from us, which leave their first impressions on the photographic plate. The distances of even these inconceivably remote stellar galaxies are not completely beyond the reach of measurement by the astronomer. Statistical relationships connecting apparent size and brightness with distance, which have been established by the aid of nebulæ of known distance, may be applied successfully in cases where the nebulæ are grouped into clusters. One such group in the constellation Coma Berenices has been studied with especial care by Professor Hubble, who has estimated the value of the order of 50 million light years for its distance. Within a small area no less than 304 nebulæ have been counted in this cluster and more than 400 have been found on photographs taken with the 100-inch telescope at Mount Wilson.

There has recently been found on photographic plates a cluster of some 300 faint nebulæ in the constellation Leo. This is the most distant cluster of nebulæ yet investigated. Professor Hubble assigns to it a distance of approximately 105 million light years.

In addition to these, and scattered all over the heavens, are thousands of nebulæ fainter still and forming a much more distant background. So far as study has gone, there seems to be a large number of nebulæ at the limits of visibility, and we cannot suppose that an end may be reached by any means now in prospect. The thought that each of these nebulæ may itself represent a stellar system leads to a conception of numbers, dimensions, and masses which will stagger even a powerful imagination. One recalls the words of Rossetti's

sonnet, picturing one gazing towards the far horizon:

"Miles and miles distant though that grey line be,
And though thy soul sail leagues and leagues beyond;
Yet leagues beyond those leagues there is more sea."

CHAPTER XXII

POWER, INTELLIGENCE, AND WISDOM REVEALED IN THE ASTRONOMICAL UNIVERSE

It is still as true as when the Psalmist wrote it first that "the heavens declare the glory of God, and the firmament showeth His handiwork. Day unto day uttereth speech and night unto night showeth knowledge." In some ways it is even truer now than it was then, because to-day the words have a grander significance than they could have had to David. To him the heavens were not so very vast nor so very remote. The stars were only glittering points set in an over-arching sphere and, for him, they and the Sun and Moon were mere appendages of the earth, of no importance except as beautiful and useful servants of mankind. Now we know an immeasurable universe compared with which our own great world itself is only the merest speck, a mote in the sunbeam.

As men have come to know more of the material universe they have had continually revealed to them something more of the glory and majesty of the Creator.

Let us mention first the enormous extent of the astronomical universe. Compared with ourselves and with the region we can fairly see around us the earth itself is certainly vast. One who has made its circuit appreciates its greatness. Let us, in imagination, leave the region of the earth and attempt the tremendous journey to the Sun. Space will not permit my discussing the various methods by which

astronomers have been able to stretch their measuring-line across the huge abyss, and so to affix their scale of miles to the great chart of the Solar System. The problem has not been an easy one, and its first approximate solution was attained by means of the transits of Venus in 1761 and 1769. Since then, various other much more accurate methods have been devised and carried out, all of which practically agree in showing that the radius of the orbit of the earth is nearly 93 millions of miles, a little more than thirty-seven hundred times the circumference of the earth. It is a distance so great that mere figures convey no adequate conception of it, and we are driven to illustrations to make it in the least intelligible. We compare it with railway journeys, and find that an express train going sixty miles an hour would occupy 177 years upon the trip, running day and night without a single stop or slackening of speed, and the fare of only a penny a mile would be nearly four hundred thousand pounds. If sound could travel through the celestial spaces at the same velocity as in our air it would require fourteen years for the boom of one of the great explosions which sometimes occur upon the Sun to reach us. If some electric cable could be stretched between the earth and Sun, capable of transmitting its telegraphic signals at the rate of 30,000 miles a second, it would be nearly an hour before the touch of the key at one end of the line would report itself at the other. Swift light itself, darting 186,000 miles each second, is eight minutes and a third upon the way. It is an immense distance, and yet across the abyss the Sun exerts its power upon the earth and controls the motion of its huge mass as it whirls along its orbit 18·47 miles a second, more than forty times as

swiftly as a cannon ball, holding it to its course by bonds of invisible attraction. Stated in round numbers the mutual attraction between the Sun and earth is a continual pull of nearly 4 millions of millions of millions of tons ; and across the yawning gulf the Sun pours the streams of radiance which we call light and heat, supplying all the energy which operates upon the surface of our globe.

Compared with the earth the Sun is vast in magnitude, so immense that, were the earth placed in the centre of its globe, the distant Moon would be but little more than half-way to its surface. Its bulk is more than a million and a quarter times that of the earth and its mass 330,000 times as great.

If the intensest heat and most dazzling brilliance may be spoken of as fire, then is the Sun a globe of fire, a fire too hot to burn in any such sense as the fires of our earthly furnaces. No fuel is being consumed, but for millions of years the gigantic globe of elementary gases has, by as yet unknown means, maintained its blaze. Every square foot of its enormous surface pours off continuously an amount of heat equivalent to more than 8,000 horse-power of energy, and maintains a temperature very much higher than that of our fiercest furnace. It seems, at first, as if we had here repeated the miracle of the "Burning Bush," and on a scale as much grander as the heavens are vaster than the earth. It is not so, however, for the end will assuredly come; but in such a process millions of years count only as minutes in a human life.

The earth and Moon are not the only attendants of the Sun. Its domain is vastly more extensive. Four planets, which in scale of magnitude are of the same order as the earth, are nearest to it; the earth

being third in distance, while Mercury and Venus revolve within its orbit, and Mars pursues its course at a distance one and a half as great as ours. Far beyond Mars revolve the major planets Jupiter, Saturn, Uranus, Neptune, and Pluto. It is a great, an immense dominion, this of the Sun—no less than 7,388 millions of miles across.

But vast as the Solar System really is, it is little more than a mere speck as compared with the universe of the stars; for the stars, which to the eye look like mere glimmering points of light and even defy the power of the telescope to give them any apparent size, are really suns—some of them certainly many times vaster than our own—all shining, not like the planets with borrowed light, but each with a special radiance of its own, and appearing small only because of their inconceivable remoteness. They are so remote, indeed, that it is possible to effect a real measurement of the distance of even the nearest of them only by processes and observations the most delicate and refined in all the range of astronomical science.

Alpha Centauri—the second nearest of all the Sun's companions—is 275,000 times as far away as we are from the Sun. The distance is so enormous that light itself is four years and four months on the way. One of our express trains would require 48 million years to make the journey, and the railway fare to this nearest of all the stars would amount, at one penny a mile, to about 105,000 million pounds. Of the rest whose distance has been measured, the three or four that come next are from two to three times as remote. From the facts at hand it can be shown beyond doubt that, among the stars which the telescope reveals, multitudes must be hundreds

and even thousands of times as remote as the nearest. Every clear night we unquestionably look upon stars so distant that the light which makes them visible must have started upon its journey before the pyramids were built.

In the heavens we find bodies in all the various stages of our system's history. There are star clusters, swarms of stars as large as the stars we see with the naked eye; there are nebulæ which are mere formless clouds of luminous gas; others that are more or less globular and partly condensed around a star-like point; some are like whirlpools.

If we classify the stars by the character of their light we find some with spectra intermediate between those of nebulæ and finished suns, others whose spectra match that of the Sun with precise exactitude, and others yet whose spectra suggest an intenser heat and a more dazzling radiance than even that of our own central orb. Still others seem to be on the downward grade and verging to extinction.

It is true that individual stars and systems indeed give clear indications that they are by no means eternal. It is not impossible that, hereafter, scientists may find out the figures that measure their existence. But as for the great whole, it must be that its duration exceeds as much the countless ages of the life of any single system as that of the entire human race surpasses that of any one man. In time, as well as in space, the Divine presence and activity declares itself as transcending all limits we can fathom.

What now is to be said of the power of God as revealed in the astronomical universe? When we consider the forces which act between the heavenly bodies, their tremendous masses and the swiftness

with which they move, we find that the figures which express their energy are utterly beyond conception.

Attempt, for instance, a comparison between the energy expended in driving across the Atlantic Ocean one of the largest vessels of the Cunard Steam Shipping Company and that stored up in the axial revolution of the Moon; we find that this stored-up energy of the slowly turning little satellite, which occupies a whole month in each rotation, exceeds the other in the proportion of more than fifty millions to one. The earth's energy of axial rotation is more than eight hundred thousand times as great as that of the Moon; and the energy of her orbital motion, as she darts along at the speed of eighteen and a half miles a second, exceeds the rotational energy by more than eleven thousand times. What shall we say, then, as to the accumulated energy of such a planet as the swiftly whirling giant Jupiter? Or that of the Sun and its attendant planets in their vast journey through inter-stellar space with a velocity at least twenty-five times as great as that of a cannon-ball? What, then, must be the total energy of all the spinning, rushing universe of stars and systems?

Again, think of the heat-energy of the universe; recall that every square yard of the surface of our Sun is pouring off continuously about as much power as that exerted by the great engines of one of the largest Cunard liners at her highest speed—*Mauretania*, 70,000 h.p., square yard Sun, 72,000—and then remember the millions upon millions of other suns as great and fiercely hot as ours.

Consider, too, the forces—the pulls and pushes—that pervade and control the universe; how in some mysterious way each separate atom of the mighty

whole is urged toward every other atom by what we call attraction.

Once more, the whole astronomical universe manifests not only power, but intelligence and wisdom. Our planetary system is an orderly organization governed by laws of extreme simplicity and beauty, laws which our human intelligence delights to search out, recognize, and apply in scientific prophecy.

One other point remains to be briefly noticed: how the unity of God declares itself in astronomical phenomena. Identity of substance and of law, similarity of plan and purpose run through the whole material universe. As to material, the only celestial specimens, the only pieces of non-terrestrial matter upon which we can actually place our hands are the meteorites which from time to time fall upon the earth. We do not find in them a single chemical element unknown upon the earth nor any combination of elements inconsistent with the laws of terrestrial chemistry. We do find, however, some new compounds in the form of minerals which are never met with elsewhere, and seem to have been formed under conditions very different from those which exist upon our planet. Their whole testimony indicates a widespread identity of matter and of law.

The evidence of the spectroscope bears in the same direction with still more force and with a far wider reach. We cannot enter here into extended explanations how the light of every shining body carries with it a record of its constitution and condition. It is enough to say that the lovely ribbon of colour which we call the spectrum, meaning an appearance, is marked with transverse lines and bands, sometimes bright and sometimes dark, and these are characters which, to those who can read

them, tell more or less completely the story of its state and nature. The word spectrum is applied not only to sun-light, but also to the light of any glowing substance when its rays are sorted out by a prism or a grating. Each substance thus treated sends out its own vibration of particular wave lengths. Now, in the spectra of the heavenly bodies, of the Sun and stars and nebulæ, we find the clear record of the presence of familiar elements. There always stand out the well-known lines of calcium, magnesium, and especially sodium, hydrogen, and iron, the same which are the most conspicuous in the spectrum of the Sun. Rowland said that if the earth were heated to the solar temperature, its spectrum would be substantially the same as that of the Sun itself. The signatures of many of our terrestrial metals are written upon some of the remotest stars as plainly as any monumental inscription. Sirius and Vega, indeed a large majority of the nearer stars, exhibit hydrogen as distinctly as any bell-jar upon a laboratory table, and in its luminous properties this stellar hydrogen is identical with the solar, and this with the earthly. The sodium of Arcturus and the magnesium and iron of Capella ring out in perfect luminous unison with the same molecules upon the earth.

So also the law of gravitation appears, with the highest probability, to be actually universal. The motions of the binary stars are precisely what they ought to be if the same attractions which control the movements of the planets are also dominant in those distant regions. There is hardly room for doubt that gravitation fully explains and rules the motions of the stars.

Other ways might be mentioned in which the one-

ness of the universe appears—the manner, for instance, in which the stars in all portions of the heavens show a consistent classification according to their spectra, the similarity of the forms and characteristics of the nebulæ, and the curious connections between stars and nebulæ. Identical appearances manifest themselves in objects and regions as far apart "as the East is from the West," separated by distances so vast that light itself must require millions of years to traverse them. In short, the universe of astronomy, inconceivably enormous as it is in space and time, is an orderly cosmos of organized activity, and its oneness illustrates and declares the unity of the Creator, the one Eternal, Omnipresent, Omnipotent, All-wise God.

CHAPTER XXIII

ORIGIN OF THE SOLAR SYSTEM

A UNIVERSAL tradition has existed, even in the earliest ages, that our Solar System was formed from primeval elements which were scattered, without order or arrangement, through the heavens. The idea of a gradual evolution of a nebula into planets is not the exclusive possession of modern scientific thought. What it can rightly lay claim to is the advancing of certain theories founded upon precise observation as to the possible modes of such formation.

Lucretius had even brought forward a theory of the fortuitous clashing together of atoms to account for the gradual aggregation of the materials of the Sun, earth, Moon, and stars. A similar tradition is to be found among the Christian writers of the earlier centuries. According to this tradition, which appears in the writings of Athenagoras, Theophilus, Basil, Ambrose, and others, matter was originally created in an elementary state, and this unformed mass was, moreover, one and not multiple. Origen and his school, with St. Augustine, agree on this point with these writers. We also find the same view expressed by Christian writers from Tatian to Hugo of St. Victor, and through Peter Lombard to Bonaventura as representatives of different schools of exegetical writers, that the Sun, Moon, and stars were at first all involved in this universally diffused mass. The exposition of such views as given in the

works of St. Gregory of Nyssa, who flourished in the fourth century, is very remarkable. Commenting on Genesis i. 2, which reads in our version of Holy Scripture: "The earth was void and empty," he says: "It is indeed written that 'the earth was invisible and uncomposed,' so that from this it should be clear that all things were disposed in potency in the first creative act of God, as a seminal force for the procreation of all things; but none of them were at that time realized. The earth was 'inanis et vacua,' as if it should be said, it was, and it was not, since its properties were not as yet united in the manner to render it concrete." And again: "Hence in the sum total of the first foundations of the world, among other existing things was the earth. But it was in expectancy of what may be called its birth, by the combination of its multiple properties; for in calling it 'invisible,' the Scripture shows that none of its properties were apparent, and in calling it 'uncomposed' it shows that it had not as yet become a concrete body, by the union of its physical properties."

Thus St. Gregory seems to have anticipated Laplace by fourteen centuries, in the central idea of his cosmogony, which is the formation of the Solar System from a diffused mass of primitive nebular matter.

The hypothesis of Laplace is founded upon a physical basis relating to certain agreements which exist among the planets, and which unquestionably prove that they are members of one closely-related family. In fact, we cannot but recognize, in the connected movements of the bodies of the System, the working out of a common physical law.

According to Kepler's first law the planets move round the Sun in elliptical orbits, the Sun being at the focus of the ellipses. But these foci are almost at the centre of the elliptical paths, which consequently differ very little from circular orbits. Again, if we consider the directions of the movements of the planets, they all rotate on their axes in the same direction, namely, from west to east. Besides this, the planets not only spin on their axes in the same direction, which direction is that also of the rotation of the Sun upon its axis, but they all revolve round the Sun in a direction identical with the common direction of rotation. In addition to the planets, more than 1,000 asteroids are situated between the orbits of Mars and Jupiter. This harmony is an overwhelming proof of their intimate connection one with another and of the operation of some physical law common to them all.

The fundamental plane to which all the movements in the Solar System are referred is that of the ecliptic, or the plane containing the orbit of the earth round the Sun. Now the planes of the planetary orbits, except some asteroids, are inclined at very small angles to that of the ecliptic, the greatest inclination of any plane being that of the path of Mercury, which is only 7 degrees. This is another indication of the close connection which exists among the members of the planetary family.

Another law which also is approximately true is one that concerns the relative distances of the planets from the Sun. Many attempts have been made to find some law regulating the relative distances of the planets from the Sun, particularly as it was thought

there was an unusually wide interval between Mars and Jupiter, separating the Inferior and Major planets. No accurate law respecting the planetary distances has yet been found, but the following curious approximation to a law was discovered by Professor Johann Daniel Titius of Wittenberg and promulgated by the astronomer Bode in 1778. Take the numbers 0, 3, 6, 12, 24, 48, 96, 192, 384, each of which (excepting the second) is double of the preceding, and to each of these numbers add 4; we thus obtain 4, 7, 10, 16, 28, 52, 100, 196, 388.

The resulting numbers, divided by 10, are pretty nearly the true mean distances of the planets from the Sun, in terms of the radius of the earth's orbit. Except in the case of Neptune, where the approximation breaks down, these numbers represent, almost precisely, the relative distances of the planets from the Sun.

BODE'S LAW

Planets.	*Mean Distance from Sun.*	*Distance from Sun according to Bode's Law.*
Mercury	0·39	0·4
Venus	0·72	0·7
Earth	1·00	1·0
Mars	1·52	1·6
Asteroids	2·77	2·8
Jupiter	5·20	5·2
Saturn	9·54	10·0
Uranus	19·19	19·6
Neptune	30·07	38·8
Pluto	39·60	—

The relative distance of Pluto from the Sun is close to that predicted by Bode's Law (38·8) for Neptune. This puts Pluto, on the average, about 900,000,000 miles farther from the Sun than Neptune. By

showing the gap which existed between Mars and Jupiter it led indirectly to the discovery of the Asteroids. Also, when Uranus was discovered, its distance from the Sun was seen to be almost exactly the number assigned in terms of the distance of the earth from the Sun. This remarkable relation between the relative distances of the planets may have some physical basis which, at present, is unknown to us.

With some of these concordances before him Laplace enunciated his famous nebular hypothesis as to the mode of the origin of the Solar System. He held that an intensely heated mass of gas once extended from the position of the Sun to a distance far beyond the orbit of the outermost planet of the Solar System. The separate portions of this nebulous mass had, in the commencement, various motions of their own. But each and every particle of matter mutually attracting and being attracted, the formless mass of independently moving atoms finally resolved itself into a vast globe of highly rarefied gas with a motion of rotation about a central axis. Such a rotation would necessarily result in a flattening at the Poles in the gaseous globe. The ultimate form would be that of a lens-shaped nebula elongated in the direction of the major axis. The gas was at first expanded by heat, but condensation took place owing to radiation at its surface. This necessitated a quickening of the speed of rotation in consequence of a well-known law in mechanics, called "the conservation of the moment of momentum," which requires that the amount of rotatory energy in any system should be always constant, for, in the motion of the mass about the central axis, three factors are involved—namely,

the mass, the angular velocity, and the distance squared from the axis. If contraction takes place and the distance from the axis be diminished, the mass remaining constant, the rotational velocity of the particle must be increased to maintain the constancy of the product. Laplace maintained that, as the mass cooled and contracted towards its centre under the gravitational pull, the centrifugal force, owing to its rapid rotation, became so great that the edges of the lenticular mass successively ceased to be continuous with the parent mass and were, in turn, abandoned as rings. These rings would, as supposed by Laplace, break into fragments, and their materials would unite about the denser portions to form globes. The same process would be suitable to the newly formed and highly attenuated gaseous globes, which would themselves, in their turn, become the parents of their satellites.

A more recent theory is that worked out by Sir James Jeans. He has studied, by an elaborate and profound mathematical analysis, the conditions of stability of rotating gaseous masses and the modes in which such masses would break up under the action of impressed forces. He writes: "But, after allowing for all imperfections, we have a tolerably complete knowledge, so far as the main outlines are concerned, of the whole change of configurations, which will be assumed in time by the rotating shrinking mass of Laplace, and on this chain there does not appear to be any room for the Solar System." His objections to the validity of Laplace's hypothesis so far as the formation of the planets is concerned are stated as follows: "First, the present momentum of the System fixes a limit to the density near the

edge of the primeval nebula, and this density is so low that matter thrown off from the edge could not condense into planets." We have seen that the product mass, angular velocity, distance squared from the axis must be constant. Mass varies directly as the product of the volume and the density. Consequently, if the volume of the mass of the Sun and the planets was originally very great, the density must have been very small. We may neglect the mass of the planets and their satellites as being insignificant, being less than one-seventh per cent. of the total mass, the Sun taking more than ninety-nine and six-sevenths of one hundred parts.

"Secondly," says Jeans, "the only form of rotational energy which is applicable to our System postulates matter being thrown off continuously and slowly, and the matter would be ejected so slowly that it could not condense." The Sun, at his present density, takes twenty-five and a half days to turn on his axis. Pluto, the furthest planet from the Sun, takes 250 years to perform one revolution around its primary. The uncondensed matter of the primitive nebula extending beyond the orbit of Pluto must have revolved still more slowly. "Thirdly," continues Jeans, "even if these objections were not valid, and matter had condensed, the masses formed would have been much greater than the planets of our system." Nevertheless, his statement with regard to the origin of the Solar System as supposed by Laplace is a cautious one—namely, that "it is probable, but by no means certain, that we must abandon the theory of Laplace." What is the theory he substitutes in its place? It is a theory founded upon the action of tidal forces and the consequent disruption of the primeval mass of gas owing to the

chance very close approach of some large star in the distant past. This action would have resulted in a stream of matter being drawn out from the equator. Such a stream would have been in a condition of unstable equilibrium, and might have condensed into nuclei at its centre and also at its ends. The gravitational action of the passing star would have caused the condensations to have described elliptic orbits, and so they would not have fallen back into the Sun. The condition of the Sun, when the planets were born, was that of a gaseous mass with high central condensation. The smallness of the masses of the planets, as compared with that of the Sun, is an indication that the original condition of the Sun was such as is here supposed. This is entirely a different state of the primeval mass from that supposed by Laplace. If we consider the masses of the planets we find that those of the middle planets of the System—namely, Jupiter and Saturn—are much larger than those of the other seven planets. This is just what would have taken place in the formation of the planets on Jeans' theory, in the condensation which would have occurred in the stream of matter ejected from the equatorial regions of the primeval Sun, by the tidal action of the passing great star. The theory also claims that the parent mass of gas should have been lenticular in form with sharp edges. This supposition fits in with that of Laplace, and is confirmed by the agreement in the planes of the planetary orbits. But instead of the breaking up of a great volume of tenuous gas by rotation, there is substituted the tidal action of a passing star upon a mass of gas very much condensed at its centre.

Considering the enormous extent of the celestial

spaces and the immense distances that separate individual stars, the occasions on which stars will approach very close together must be extremely rare. Consequently, planetary systems such as our own, if the hypothesis of formation advocated by Jeans be correct, must be extremely uncommon.

Finally, although there exist such serious difficulties to the acceptance of Laplace's hypothesis of the origin of the Solar System, it appears to accord with the formation of a whole system of suns such as our Milky Way from a primitive revolving nebula, probably spiral in form. It would thus only have been displaced as a theory of cosmogony of a comparatively small system to be raised to the elevation of honour as an explanation of the origin of thousands of millions of suns.

CHAPTER XXIV

THE ORDERLY ARRANGEMENT OF THE UNIVERSE

By the system of the stars is meant that system of which our Sun forms one unit. It extends as far as the Galaxy and consists of more than 2,000 million suns.

Taking as our unit of measurement the distance that light, which has a velocity of 186,000 miles a second, travels in a year, or a unit slightly less than six million million miles, the more distant clouds of the Galaxy lie at a distance from us of thousands of light years. Astronomers are generally agreed that the stellar system or universe, as we know it, is in the shape of an oblate spheroid or ellipsoid, something like a lens in its outline. The Solar System lies not far removed from the median plane of this elongated congeries of stars. There also lie in this plane the more open star clusters, such as that of the Pleiades; the diffuse nebulæ, of which the nebula in Orion is one of the most beautiful examples; the planetary nebulæ, such as the ring nebula in Lyra, with the Novæ from which they have probably been formed; and the dark nebulosities.

The globular clusters, too, of which that in Hercules, some 30,000 light years distant, is a type, though not in the Galaxy, are evidently connected with it. The spiral nebulæ, however, seem to be objects outside the Milky Way regions. Some astronomers are of the opinion that they are external galaxies.

But, excluding such nebulæ, all the other luminous

objects in the heavens are arranged and distributed in an orderly manner with regard to the Galaxy as a luminous circle on which the stars are concentrated. A system implies and claims orderly arrangement. It presupposes law, and the gravitational arranging of the stars is a fundamental condition of the stellar Galaxy. It is based on uniformity. The stars of our system are not an accidental arrangement, but one that is the effect of the operation of definite processes, one that possesses community of origin and essential unity in its constituent materials.

Further, not only are the nearer clusters—such as that in Ursa Major, that in Orion, those of the Pleiades and Hyades in Taurus—endowed with a common direction of proper motion, but all the nearer stars are moving in two great processions in two different directions, the two streams intermingled together, but without collision or mutual interference. That the stars of our system possess community of origin is shown by the study of the nebulæ and of the physical connection of the stars with the nebulæ. In the year 1812 Sir William Herschel, one of the greatest observers, recognized, by an intuition of genius, an orderly sequence among the nebulæ and the stars enveloped in them which he had observed. Modern photographic evidence lends weight to his principal conclusions.

The nebulæ can be arranged in the order of a gradual state of condensation from filmy structureless clouds, through more condensed nebulæ, to nebulæ connected with the stars, such as the planetary nebulæ, and finally rich star clusters. The evidence of the spiral nebulæ is conclusive that the stars are physically connected with nebulæ. There is every reason to believe we are observing

the process of formation in external galaxies, whose distance may be measured in millions of light years.

There is also unity in the materials which form the nebulæ and the stars of the sidereal Galaxy. The same materials are found by the spectroscope in the celestial spaces, though in an orderly sequence of predominance. In the green or gaseous nebulæ are observed helium, hydrogen and nebulium. Then follow the bluest and hottest stars, with helium and hydrogen as their main constituents; the white stars, in which hydrogen forms the principal feature. Next come the yellow stars, such as our Sun, with calcium and metallic vapours in their atmospheres; and, last of all, the red stars, in which the temperature is so low as to permit of the formation of chemical compounds. Not that the red stars are on the lowest step of the evolutionary ladder, for there are red stars, like Betelgeuse and Antares, with a volume capable of containing more than 20 millions of our suns, of extremely tenuous density, but, owing to their size, of great apparent brightness; and there are also faint red stars approaching total extinction.

The process of evolution seems to be through giant red and yellow stars to white and blue stars on the ascending scale, and then in reverse order through yellow and red stars of continually diminishing luminosity and increasing density.

In former ages, before the invention of the spectroscope and of the photographic plate, star-gazers pictured to themselves the System of the planets and the few thousands of stars visible to the naked eye as founded on the earth as a centre. But even with this scanty and insufficient outlook, the mutual motions of the planets under the obvious reign of law, the apparent movements of the Sun and of the

Moon across the sky gave them some partial knowledge of a definite and orderly arrangement. Ptolemy, Kepler, Copernicus, and Newton successively reduced to a code the laws by which their motions were governed. But harmony, uniformity, orderly arrangement is the effect of direction by an Intelligent Cause. For unintelligent instruments can be uniformly directed to an end only by an Intelligent Cause. And in the movements of the planets and of the stars we see an orderly arrangement of unintelligent creatures or instruments. We are compelled, logically, to conclude that this arrangement is due to the action of an Intelligent Cause.

But with our increased knowledge of the processes and laws which are evident in the celestial spaces in the system of the stars, how much more powerful and convincing becomes this argument for Design and for the existence of a First Intelligent Cause based on the orderly arrangement of the universe.

Further, in the system of the nebulæ and of the stars we behold change, modification, gradual transformation according to an evolutionary order. And the science of astronomy, when it deals with the origin of worlds, assumes gradual change and a transformation from a primeval state—that is, from a nebulous mass supplied with motion to the formation of clusters and systems and Milky Way of stars.

All these changes philosophy groups under the comprehensive title of Movement. Now, whatever is moved requires an active agent to cause the movement. To state the matter as a general principle: "That which changes has not within itself the adequate reason of its change"; or, to put the principle otherwise, "All change is dependent on some being other than that which changes." The scholastic

philosophers expressed this axiomatic truth in the brief maxim: "Whatever is moved is moved by something else." It follows, then, that there exists outside an ever-changing system of stars a Being Who is not Himself subject to change. Only thus can philosophy account for all the changes in our material universe. This Supreme Being, whose nature is exempt from the changes and modifications which we observe in all the physical processes that are subjected to our investigation, is the Pure Activity Whom we adore and revere as the Creator of the material universe.

The arrangement and order, the immensity and beauty of this enormous system of stars and nebulæ give us some inadequate glimpses of the attributes of this First Intelligent Cause—His Power, His Wisdom, His Omnipresence, His Omniscience, His Majesty. Before His attributes as God the whole of the starry firmament pales into insignificance. Compared to His immensity all the untold millions of heavenly bodies are but as one drop in a mighty ocean. And He is beyond all imaginable space, perfectly and completely, with all the perfections which are eminently contained in Him. He is everywhere in nature and immeasurably beyond the furthest imaginable star. As the inspired Psalmist sings: "Great is the Lord and greatly to be praised, and of His greatness there is no end."

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